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Proceedings of the National Ocean Survey

Eighth

Hydrographic Survey Conference

January 12-16, 1981
Norfolk, Virginia

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
John V. Byrne, Administrator
National Ocean Survey
Rear Admiral H.R. Lippold, Jr., Director

November 1982

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PREFACE

This Eighth Annual National Ocean Survey Hydrographic Survey Conference was distinguished by the participation of the Defense Mapping Agency, the U. S. Naval Ocean Research and Development Activity, the Canadian Hydrographic Service, and the Oceanography Department of the Naval Postgraduate School. By presenting papers and sharing their experience during discussion periods, members of these agencies have played a key role in the success of these proceedings.

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National Oceanic and Atmospheric Administration
National Ocean Survey
Atlantic Marine Center
Rear Admiral R. H. Houlder, NOAA
Director

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MONDAY, JANUARY 12, 1981

OPENING REMARKS

REAR ADMIRAL RICHARD HOULDER, Director of the Atlantic Marine Center: It's my privilege and honor to officially open this 8th Hydrographic Conference on behalf of the Director of the National Ocean Survey. Unfortunately, Admiral Lippold was not able to be with us this morning. He's wrestling with some of our budget problems. We will know shortly whether we can send our ships out the next two weeks or not.

I think that is probably a worthwhile reason for being back in Rockville for a short period.

Admiral Lippold will be joining us, however, tomorrow afternoon. He will be staying with us for two or three days.

There are quite a few people in the audience who deserve recognition. However, I would just like to introduce two or three of the key individuals.

First, if Steve MacPhee, the Canadian Dominion Hydrographer would stand up.

Steve is down not only for the Hydrographic Conference, but for the US/Canadian Hydrographic Commission. He has his regional hydrographers with him, and several other people, and we are very happy to welcome them and to have them here with us.

I would also like to recognize Admiral Ross Williams, the Oceanographer of the Navy, and the key adviser to the Administrator of NOAA. And the third one I would like to recognize is Mr. Bob Beaton, from DMAHTC, who I believe knows more about nautical charting in both NOS and DMA than probably most of us in this room.

These conferences started about 8 years ago, about 1973, as a processing conference. It was mainly instigated due to the introduction and the advent of automation.

At that time we were concentrating mostly on the data acquisition phase of it and the processing phase. Today we are kind of in the final throes of the first cycle in the final efforts towards the data application, the cartographic phase.

However, during this period of time, the advances in automation and electronics have been such that, today we are faced with just as much of a challenge as we were faced with in 1973. We are now faced with new possibilities in data acquisition, data processing, data application. Therefore, I believe that the reasons for a meeting such as this are just as important today as they were then.

We have a little dilemma in these meetings, in that they started as a workshop; they have gradually evolved into a combination of formal presentations and workshops. We are not sure just what the best format is. Therefore, we would be very pleased if you would comment during this meeting, or afterwards, on whether we have struck a proper balance between formal papers and workshop activities.

This week you will find that the first two or three days are more formalized; the last two days are workshop activities.

Next, I would like to introduce the members of the conference committee, mainly so you will know who to go to if you have any problems. If you have any compliments, you can come to me. (Laughter)

You have already met Commander Karl Kieninger, who is chairman of the group.

I would next like to introduce Mrs. Margaret Kerr, our Administrative Officer.

Lieutenant Commander Dave Yeager,

Lieutenant Commander Max Ethridge,

And Rudy Sanocki.

For the official welcome to the meeting, we are honored today to have the Mayor of the City of Norfolk.

Mayor Thomas has been a strong supporter of our activities and has shown a great amount of interest. It is my honor now to introduce Mayor Vince Thomas, Mayor of Norfolk.

Address by Mayor Vincent Thomas

Mayor, City of Norfolk

MAYOR THOMAS: Thank you, Admiral Houlder.

Admiral Munson, Admiral Williams, Mr. MacPhee, distinguished representatives of the National Ocean Survey, and good friends, ladies and gentlemen: I am delighted to welcome this distinguished meeting to Norfolk. Admiral Houlder was going to take credit for the positive results of the meeting. I am here in sort of a funny position to figure out whether or not I should take credit for the weather. (Laughter)

This morning I left my home in bright sunshine, and moved towards Virginia Beach to a breakfast meeting at 7:30. When I went over the Virginia Beach line, there immediately arose a dark cloud and snow flurries, so we are going true to form in having in any 24-hour period about all of the different forms of weather that we can deliver.

So, you've got further treats in store for you, I'm sure, for the rest of the day.

It is a pleasure to see old friends back in Norfolk. Admiral Munson, who was here at the Atlantic Marine Center not too long ago, and Admiral Williams, who, like many of our good Navy friends, move in and out of Norfolk on regular occasions, and he was here as commanding officer of the USS SPEAR.

I'm delighted to be able to speak to you this morning. We are having a little political flap here in Norfolk about giving our members of council and the mayor raises, and I've been searching around for reasons to justify a little money to take care of inflation, and so I'm going to tell the council that I have now been required to become an expert on the Interpretation of Satellite Imagery Related to Bathymetric Features. This will give me a great deal of status before council. (Laughter)

We do welcome these gatherings of highly trained and educated people who are dealing on the frontier of technology. We feel that our community does create an atmosphere that should attract further activity in these areas, especially those related to the research and development of our oceans.

So, I'm delighted to have you here. Many of you are among the men and women who staff NOAA's Atlantic Marine Center here in Norfolk, and as such you are not really guests at all, but honored citizens, and taxpayers -- especially taxpayers -- of our community. I guess it is no secret by now that we intend to do all we can to keep you here if at all humanly, or maybe I should say politically, possible, and of course, we extend a special welcome to any of you who might be from Charleston (Laughter), our fine neighbor to the south. We hope that your future contacts with the Atlantic Marine Center will be here in Tidewater, Virginia.

Another reason that I particularly welcome all of you is that a city like Norfolk truly understands and appreciates the work and dedication of people like you.

Norfolk is now just a year away from its 300th birthday, and we are more mindful than ever as our tricentennial year approaches that our very reason for being is our port and its relationship to the oceans.

We were created by the Virginia General Assembly three centuries ago because the assembly saw in its wisdom the need for a port in these parts. If those legislators could only see us now.

Norfolk and our fellow Hampton Roads cities are now among the most important port communities in the world. We have a mix of maritime activity that perhaps cannot be surpassed anywhere in the world; the free world's largest Navy Base, shipyards, both public and private, universities and other academic institutions with ties to the sea.

We are very proud of the growing excellence of the School of Oceanographic Studies at Old Dominion University; ocean-related industry of all sorts, the world's largest coal port, which now is almost bursting at the seams, and if you have been in Hampton Roads lately, or in the Lynnhaven area, you will know what I'm talking about there. I think the count is now about 130 ships waiting for coal. Fishing activities and all other marine-related activities.

Surely the Atlantic Marine Center is vital to us in this mix of activity, and fits very well with other agencies working in the fields of oceans' research and development, like the Virginia Institute of Marine Science, the Fifth Naval District, and the Fifth Coast Guard District. Also NASA is doing work in this area, of course.

Indeed, it was this very mix of public and private, commercial and military port activities which convinced Captain Jacque Cousteau to move his base of operations to Norfolk and the CALYPSO is here now. I think Captain Cousteau and some of his people are up in Canada on a land-based expedition, but the CALYPSO is undergoing extensive repairs before her next operation.

Incidentally, the Atlantic Marine Center has been very much involved with Captain Cousteau in his operations, and has been very cooperative in helping with some of his problems, and I would like publicly to thank you and your staff, Admiral Houlder, for everything that you have done in connection with the movement of the Cousteau Society operations to Norfolk.

As a port city, we have deep appreciation for the men and women who have dedicated their lives to the safe use of the seas and the waterways. The charting of our waters is a vital activity and you should be proud of your profession.

As mayor of this historic seaport city I thank you for your work, which surely hasn't been made easier by the enormous number of these colliers around the port.

And as a graduate of Matthew Fontaine Maury High School, and also of the Virginia Military Institute, where Commodore Maury taught for a time, I can assure you that I know the value of map making. So, I can say with warmth and sincerity

to those of you who live among us, to those of you who live beyond our city limits, and indeed to those who have come from beyond our national borders, we are glad to have you in the business that you are in, and we are glad to have you meeting in our city.

Welcome.

CDR KIENINGER: Thank you, Mayor Thomas.

MT MITCHELL AND THE YUCATAN STRAITS

CDR Ludvik Pfeifer
Executive Officer
NOAA SHIP MT MITCHELL

ABSTRACT. The NOAA SHIP MT. MITCHELL conducted two Hydrographic Surveys in the Yucatan Straits during July and August 1980. The surveys were conducted using Loran C as the positioning system interfaced to the standard Hydroplot system. This system worked effectively and efficiently.

1. INTRODUCTION

Because of a shortfall in operating budget, the National Ocean Survey (NOS) was facing the prospect of having to lay up the pride of its hydrographic fleet, NOAA SHIP MT. MITCHELL, in the last quarter of Fiscal year 1980. To the rescue came no lesser outfit than the United States Navy, with a proposal to buy 36 sea days of MT. MITCHELL's for a project in the Yucatan Strait. Accordingly, the MT. MITCHELL was "hired out" to the U.S. Naval Oceanographic Office (NAVOCEANO) in a perhaps unprecedented venture of inter-service cooperation.

The MT. MITCHELL is a "Class II" ship of the NOAA Fleet whose vital statistics are; length 231 feet, beam 42 feet, displacement 1,800 tons, and age 12 years. The ship was designed for hydrographic surveying operations and is equipped with the standard NOS Hydroplot system for the acquisition and initial processing of hydrographic data. The MT. MITCHELL operates out of the Atlantic Marine Center (AMC), Norfolk, Virginia.

The project to be undertaken consisted of an estimated 4,000 nautical miles of reconnaissance hydrography on the wrong side of the median line through the Yucatan Strait, i.e., inside the Cuban economic zone and as close as 15 nautical miles to Cabo San Antonio, Cuba. Given the international situation at the time, we were convinced that what the U.S. Navy really had in mind was to use the MT. MITCHELL for "flak bait". Our fears were somewhat allayed with the addition of a NAVOCEANO observer, the ever-amiable and super-competent Bill Anderson, to the ship's complement.

2. POSITIONING CONTROL

The objective of the Yucatan Strait Project was to delineate the bottom to the depth of 1,000 fathoms at the survey scale of 1:200,000. As a spinoff, the project would also conclusively disprove the existence of several "seamounts" which appear on the charts of the area. The fruitless search for these seamounts has been a standing "mission of opportunity" for the MT. MITCHELL in past transits through the Yucatan Strait.

Given the location and requirements of this project, the positioning system used for this hydrographic survey was the Loran-C (chain "7980") with master and slave stations as follows:

Station	Location	Latitude	Longitude
Master	Malone, FLa	30°59'38.23"N	85°10'09.06"W
W	Grangeville, LA	30°43'32.48"N	90°49'42.69"W
X	Raymondville, TX	26°31'54.02"N	97°49'58.59"W
Y	Jupiter, FL	27°01'57.32"N	80°06'53.71"W
Z	Carolina Beach, NC	34°03'45.61"N	77°54'47.20"W

The "X" (29xxx) and "Y" (44xxx) slaves were used as the primary slaves as this pair had the best intersection angle. The above listed positions are based on NAD 1927.

Aboard the ship, the INTERNAV LC-204 receiver was used to feed the observed Loran-C data into the Hydroplot system. As a check, the Northstar 6000 receiver was used for direct comparison of the observed Loran-C rates. In addition, periodic "calibrations" of the Loran-C positioning data were obtained through the use of the Navidyne ESZ-4000 Satnav receiver using satellite passes between 20° and 70° elevation (See table 1).

3. FIRST CRUISE

The project was planned to be carried out in two cruises, with an intervening inport in Miami, Florida. The ship sailed for the first cruise from Norfolk on 22 July and put into Miami on 7 August, one day earlier than scheduled because of the necessity to run away from hurricane Allen. In the course of this first cruise, 2074.5 nautical miles (NM) of mainscheme, 576.5 NM of crosslines and 13.0 NM of developments were accomplished, for a total of 2664 NM of hydrography. This high level of productivity (264.5 NM/day) was possible because of excellent weather conditions which prevailed in the project area prior to the approach of hurricane Allen.

4. HURRICANE ALLEN

The first hurricane of the 1980 season was late in coming, but when it did finally come, it packed a record-setting wallop. Its approach right up the Caribbean "hurricane alley" toward the Yucatan Strait was monitored with increasing apprehension. While Allen aimed right for the project area, its timing, at least, was right. Operations had to be broken off only one day earlier than planned. While enroute to Miami through Florida Straits, 200 NM away from the storm center, the MT MITCHELL still had a good taste of Allen's fury in battling gale force winds and 10 - 12 foot seas.

5. SECOND CRUISE

The ship sailed for the second cruise of the project from Miami on 12 August and returned to Norfolk on 30 August. The second cruise produced 2025.0 NM of mainscheme, 495.0 NM of crosslines and 291.5 NM of developments, for a total of 2811.5 NM of hydrography. Again, the prevailing excellent weather conditions permitted a high level of productivity (247.1 NM/day).

6. PROJECT STATISTICS

The monthly statistics for the project are:

JULY	AUGUST	TOTAL	
1229	4247	5476	LNM Sounding Line
1365	7785	9150	SNM Sounding Line
100	567	667	MISC., NM Steamed
1096	1348	2444	TO & FM: NM Steamed

7. SUMMARY

Both surveys were completed in the allotted time. The bottom configuration was well delineated without any indication of the existence of the charted dangerous seamounts. Thorough development of individual features was not attempted.

The use of Loran-C time delays by the HYDROPLOT system worked well and permitted the full utilization of the system's features. The on-line data gathering went smoothly with only one "lane jump" being experienced during the entire project. Based on the effectiveness of this control system, it is recommended that it be considered for future charting of small scale, deep water surveys.

Type of Comparison	Sample Size	Mean	Standard Deviation
Visual to L/C	14	TD1 = +1.214 TD2 = +0.228	0.225 0.156
SATNAV TO L/C (20°-70°)	8	TD1 = +0.564 TD2 = +0.841	0.971 1.424
All SATNAV Fixes	16	LAT = 24°36.58'N LONG = 82°54.72'W	0.174 0.630
All On-Line, Day SATNAV to L/C (20°-70°)	123	TD1 = +1.27 TD2 = -0.01	5.296 2.973
All On-Line Night SATNAV to L/C (20°-70°)	103	TD1 = +1.16 TD2 = +0.15	1.605 1.162
Massaged on -line, Day SATNAV to L/C (20°-70°)	---	TD1 = +1.26 TD2 = +0.10	1.675 1.185
Massaged On-Line, Night SATNAV to L/C (20°-70°)	---	TD1 = +1.16 TD2 = +0.15	1.605 1.162

TABLE 1. SUMMARY OF LORAN-C COMPARISONS

DISCUSSION

LCDR JONES: At this time I would like to open it up to any questions.

No questions. Thank you very much.

CAPT TRAUSCHKE: Thank you, Ron. I just might add that Cuba did not provide much of a relief for a storm the size of Allen.

We were well over 200 miles from the eye at any time, and it was quite nasty one night there.

DMAHTC's SUPPORT TO NATIONAL OCEAN SURVEY LORAN-C CHARTING

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ABSTRACT

The selection of Loran-C as the primary radionavigation system for the United States Coastal Confluence Zone (CCZ) requires, by joint agreement, that the Defense Mapping Agency Hydrographic/Topographic Center provide corrections to Loran-C lattices overprinted on National Ocean Survey (NOS) charts. Additional Secondary Factor (ASF) Corrections to warp the lattices are necessary if the system is to meet ¼-nautical mile or better positioning accuracy required by the Department of Transportation (DOT) and specified in the 1977 National Plan for Navigation.

The Coast Guard, which has statutory responsibility for the Loran-C Navigation System, expects it to be the principal aid to navigation for civil use in the CCZ until the year 2000. For Department of Defense (DoD) purposes the system will be replaced eventually by the NAVSTAR Global Positioning System (GPS).

This paper reviews future plans for refinement of the techniques to compute ASF corrections, as well as past and present computational methods. In addition, it examines the status of the Loran-C Navigation System and the status of NOS charts which support the system.

The U.S. Coast Guard has surveyed critical areas in the CCZ to verify the accuracy of Loran-C NOS chart lattices. An example survey in the offshore area of the west coast is depicted and discussed.

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DMAHTC's SUPPORT TO NATIONAL OCEAN SURVEY LORAN-C CHARTING

Introduction

On May 16, 1974, the Secretary of Transportation, with the advice of the U.S. Coast Guard, publicly announced the selection of Loran-C as the government-provided radionavigation system for the U.S. Coastal Confluence Zone (CCZ) and the Great Lakes. An annex, to this effect, was published in the Department of Transportation (DOT) National Plan for Navigation and was published as a notice in the July 19, 1974, Federal Register.

The system will provide 95% assurance that a vessel can fix its position to a predicted accuracy of ¼ nautical mile (NM) within the Zone. This accuracy requirement is instituted so that a vessel will be navigated safely along a track to its destination or within a designated shipping lane. Existing lanes vary from 1 NM at the harbor entrances and in the Gulf of Mexico Fairways to 5 NM at the outer limit of the CCZ. The CCZ is defined as:

> "the seaward approaches to land, the inner boundary of which is the harbor entrance and the outer boundary of which is 50 nautical miles offshore or the edge of the Continental shelf (100 fathom curve) whichever is greater."

The accuracy requirement affects the cartographer as well as the mariner. Therefore, the National Ocean Survey (NOS), which publishes

charts for the CCZ, engages in a program with the U.S. Coast Guard (USCG) and the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) to provide the coastal navigator with charts overprinted with lattices which meet ¼-NM accuracy requirement.

The accuracy of the lattice depends upon knowledge of the exact signal transit time between the Loran-C transmitting antenna and the receiving antenna. To achieve this accuracy the lattice is adjusted to compensate for the phase retardation of the signal as it passes over an all seawater path as compared to free space; and to compensate for an additional phase retardation when the signal passes over land paths or partial seawater-land paths. These errors are known as the Secondary Factor (SF) and the Additional Secondary Factor (ASF) respectively.

This paper presents an overview of the Loran-C Radionavigation System, the charts which support the system; and the methods used to derive ASF corrections which are used to warp the chart lattices which would otherwise be in error by the magnitude of the ASF.

JOINT AGREEMENT

At present, with respect to Mapping, Charting, and Geodesy (MC&G) products, a quasi-official agreement, consisting of correspondence and memoranda, exists between the USCG, DMA, and NOS. An official agreement which outlines the roles and responsibilities of the respective agencies is being published. Excerpts from this agreement defining Agency tasks are outlined below.

The USCG, as operator of the Loran-C radionavigation system, will coordinate all civil, and with the advice of the Department of Defense, military MC&G production relating to the system. It will conduct surveys to insure that Loran-C coverage exists with respect to envelope-to-cycle difference (ECD) and signal-to-noise ratio (SNR). To allow for timely production of coastal charts, the USCG will be responsible for the verification of ¼-NM accuracy, (95% confidence or 2dRMS), for all coastal Loran-C service. In conjunction with NOS, it will assist in surveys of coastal waters of the United States to allow production of Loran-C charts meeting the MC&G standards set forth above. USCG will provide funds to NOS for surveying systems and Loran-C receivers needed for their participation in the MC&G activity.

DMA, for Loran-C civil needs, will prepare grid predictions from its data base. Based on analysis and verification of the predicted grid from a USCG and/or NOS survey, it will produce revisions to the initial grid predictions. DMA will print charts with the revised data for the NOS geographical areas of charting responsibility, and will provide the data directly to NOS (with a copy to USCG) for charting Loran-C lattices in the contiguous U.S. maritime regions. Further, DMA will act as a central collection point for all Loran-C information. DMA will use this information to update its data base and thus improve MC&G products in the future. Finally, DMA will prepare, distribute, and periodically update unclassified ASF tables for U.S. waters as specified in the Joint Chiefs of Staff (JCS) Master Plan for Navigation.

NOS will prepare and distribute Loran-C charts for U.S. coastal waters based on data received from DMA. In conjunction with the USCG, NOS will participate in Loran-C comparison surveys of U.S. coastal waters to enable production of Loran-C charts meeting MC&G standards. There will be no charge for use of NOS vessels on these missions. Further, whenever possible, NOS will provide equipment and operators for geodetic control of surveys accomplished either by NOS or the USCG, as well as necessary recovery and preparation of control points.

Suffice to say that, although the future tense is used in the preceding paragraphs, the actions are actually being carried out.

BASIC PRINCIPLES OF LORAN-C

Loran-C is a long range, hyperbolic, radionavigation system, employing time difference measurements of signals received by the navigator from at least three ground transmitting stations. One transmitter is designated the master and transmits a group of short pulsed signals of radio-frequency energy. Two or more secondary stations receive these signals and use them to synchronize their transmissions. At the proper respective times, each secondary station transmits a group of pulses similar to those transmitted by the master station. The signals are received aboard ship where the differences in times of arrival of the master signal and various secondary signals are measured and displayed on the indicator portion of the Loran-C set. The measured time difference (in microseconds) between receipt of the master signal and that of any one of the secondary signals represents a hyperbolic line of position. A Loran-C fix is obtained from two or more time difference readings. When plotted on a chart, the intersection of the

resultant hyperbolic lines defines a geographical position. Special Loran-C charts that display the hyperbolas are used for Loran-C navigation.

It has become possible in recent years to resolve a Loran-C fix without plotting on the special charts. This is accomplished by using digital computers specifically programed to convert the time difference readings to geographic coordinates. The time difference readings are entered in the computer either manually or automatically. The computed geographic coordinates are displayed by the receiver printed on paper, or stored on tape (i.e. magnetic or punched paper) for future analysis.

LORAN-C GENERAL SPECIFICATIONS AND PARAMETERS

The following parameters were used in the baseline length computation.

a. Signal propagation: Use the velocity of light in free space as 2.99792458 (10^8) meter/second and an index of refraction of 1.000338 at the surface for standard atmosphere.

b. Phase of the groundwave: As defined in the National Bureau of Standards (NBS) Circular 573.

c. Conductivity: Sigma = 5.0 mhos/meter (seawater). Baseline electrical distance computations were made assuming a smooth, all seawater transmisssion path between stations.

d. Permittivity of the Earth: e_2=80 (for seawater).

e. Altitude in meters h_2=0.

f. Parameter associated with the vertical lapse of the permittivity of the atmosphere: a = 0.75.

g. Frequency: 100 kHZ.

h. Spheroid: WGS 72 (equatorial radius: a = 6378135.0 meters, polar radius: b = 6356750.5 meters, flattening: f = (a-b/a = 1/298.26).

All operating Loran-C transmitting stations use a cesium beam frequency standard, the AN/FPN-54 Timer and the AN/FPN-60 Transmitter Control Set as basic timing and control equipment.

Predicted coverage: Derived from a combination of geometric limits and range limits. Where data are available, the predicted coverage may be modified to reflect real-world observations.

Clarinet Pilgrim: A communications system transmitted on Loran-C using pulse position modulation of pulses 3 through 8 of the pulse group. Modulation is balanced ± 1.0 microsecond.

TTY2: A communications system similar to Clarinet Pilgrim except pulses 1 and 2 are modulated.

Two Pulse Comms: A communications system similar to Clarinet Pilgrim except pulses 7 and 8 are modulated.

Geometric fix accuracy limit: Contour showing where a receiver, capable of furnishing time-difference (TD) readings with a standard deviation of 0.1 s, will provide a two line-of-position (LOP) fix accuracy of 1500 feet, 2 dRMS (95% confidence). This calculation considers the crossing angles of the two LOPs as well as the gradient (microsecond/nautical mile) of the hyperbolic grid.

Range limits: Determined from a combination of atmospheric noise, manmade noise, and signal strength. The predicted atmospheric noise

level is calculated for a typical point in the coverage area. The 95% noise levels for each 4 hour period of day for each of the 4 seasons as given in the World Distribution and Characteristics of Atmospheric Radio Noise documents of the Xth Plenary Assembly, Geneva, 1963 (CCIR Report 322) are used along with the methodology of calculation given in that report. Prime sources of atmospheric noise are electrical storms and other natural phenomena.

Noise: Manmade noise can be very significant in some areas and must be considered when determining the useful range of Loran-C. Sources of this type of noise are industrial equipment, radio transmissions, and, to a considerable extent, Loran-C signals from other chains. Due to other Loran-C signals, effective noise figures should be increased in areas where adjacent chains generate relatively strong interfering signals.

Signal to Noise Ratio: To determine the strength of the Loran-C signal, the power output of the transmitting station is used as a starting point. The predicted signal strength, coarsely corrected to reflect the conductivity of the path traveled, is combined with noise to determine the relative signal strength or signal-to-noise ratio (SNR). Where available, real-world observations may take precedence over calculated value of SNR. A SNR of one to three is used to define coverage.

LORAN SCHEDULES

On March 1980, original plans for expanded Loran-C service throughout the Coastal Confluence Zone and Great Lakes area as contained in

DOT's National Plan for Navigation (NPN) were completed. This expansion was accomplished by construction of 13 stations, which combined with 5 existing stations, formed 6 new Loran-C chains.

Loran-C service under the NPN was completed as listed below:

RATE	Chain	Action	Date Implemented
9940	West Coast	Operational	APR 77
7960	Gulf of Alaska	Operational	JUN 77
5990	Canadian West Coast	Operational	SEP 77
9960	Northeast	Operational	SEP 78
7980	Southeast (except Z)	Operational	DEC 78
9930	East Coast	Terminated	SEP 79
7980	Zulu	Operational	OCT 79
8970	Great Lakes	Operational	MAR 80

In addition, the Canadian East Coast Chain, Rate 5930, became operational on May 31, 1980.

As part of this Loran-C expansion the NPN calls for the phase-out of all U.S.-operated Loran-A stations. The Loran-A chains which have ceased operations or are scheduled for closure are as follows:

Overseas		Western Domestic	
Iwo Jima/Okinawa	31 DEC 77	Aleutian Islands	1 JUL 79
Mariana Islands	31 Dec 77	Gulf of Alaska	31 DEC 79
Marshall Islands	31 DEC 77	Hawaiian Islands	1 JUL 79
Estaca de Vares	31 DEC 77	U.S.West Coast	31 DEC 79

Eastern Domestic			
West Indies	31	DEC	80
U.S. East Coast	31	DEC	80
Gulf of Mexico	31	DEC	80

CHART COVERAGE IN THE CCZ

At present, DMAHTC has provided NOS with approximately 400 charts. These charts include first editions and revised editions. As shown in figure 1, the U.S. portion of the CCZ is covered by ASF latticed charts for each rate depicted. The annually published NOS chart catalogs list NOS charts overprinted with ASF corrected lattices. Each chart contains one of the following notes:

> "The Loran-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are presently compensated only for theoretical propagation delays, which have not yet been verified by observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided"
>
> or
>
> "The Loran-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are compensated with propagation delays computed from observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided."

BACKGROUND AND DESIGN OF THE LATTICE CORRECTIONS PROGRAMS

These programs are based on two fundamental concepts of radio theory: (1) radio waves travel outward from the transmitting antenna along radial paths and (2) these paths are great circles over the Earth's surface.

The low frequency, 90 to 110 kHz, of the Loran-C Radionavigation System is affected significantly by the electrical properties of the Earth. The effect is a decrease in velocity and an increase in propagation time. This phase retardation of radio wave is a function of ground conductivity. The values of phase retardation for a given ground conductivity are tabulated in the National Bureau of Standards (NBS) Circular 573; and they are the bases for computing theoretical ASF.

A great circle approximates a geodesic or straight line; therefore, its path can be defined by geodetic points. Points on the great circle may be used as control points to insure that the proper azimuth and distance are maintained regardless of chart projection and scale on which the great circle may be plotted. The technique to select any point and distance is incorporated in the ASF Correction Programs.

A great circle drawn on the appropriate chart or charts from the Loran-C station coordinates to the area under consideration spans various segments of land and water. Each segment will have a specific conductivity and distance. The total of these conductivity segments will determine the total phase retardation of the path. The actual measurement, done by either manual measurement or digitizing, provides the raw data for computation of ASF. After the raw data has been put in the proper format it is entered into a program which computes theoretical ASF by Millington's Method. It is based on the principal of reciprocity which states that in a linear, uniform propagation medium, the response of the medium to a source is unchanged when the source and the receiver are interchanged. The

direction of a path from a source across a medium does not affect the response of the medium. This algorithm predicts a phase delay by computing a correction from source to transmitter and then a reciprocal correction. The values of the two corrections are averaged. The two values are not identical because the conductivity segments are biased, depending upon their proximity to the source. The amount of bias with respect to distance applied to the ground conductivity is set forth in NBS Circular 573 which is referred to above.

The WARPED LATTICE PROGRAM, developed in conjunction with the Naval Oceanographic Office, contours ASF corrected lattices on charts. Figure 2 depicts the production process. This program involves four basic stages:

- data preparation-inputs gridded data, interpreting for missing points.
- computation of contour grid line intersections
- generation of output for plotters
- chart to chart paging and edge matching.

To generate a hyperbolic lattice with the ASF correction included, this Program consists of three basic programs. They are:

- ASF Grid
- TD Grid
- Merge

The ASF GRID Program is a modification of the ASF Plot Program which DMAHTC currently uses to generate ASF correction values along azimuth lines radiating from the Loran-C transmitter. These values are used to

compute a grid of ASF corrections at 5' intervals of latitude and longitude. In preparing the input to this program the coverage area of the product chart must be broken down into smaller computational areas no larger than 8^{o} on a side. These areas are then gridded one by one in the program. After the last area is computed, the data is sorted to produce one large grid covering the entire product chart.

The TD GRID PROGRAM requires two input tapes (Master and Secondary) of gridded data, sorted according to increasing latitude and longitude. The area can be no larger than 4^{o} on a side for a 5' grid with overlap of 10' on each side to facilitate border matching. The program generates a gridded tape of TD values which have been corrected for ASF. This gridded tape is used for input to the MERGE Program.

The MERGE PROGRAM changes the format of the TD GRID Program and generates a plot of TD's at intervals of 5' of latitude and longitude. This warped lattice, consisting of a computer listing and tape, for the chart under consideration, is sent to NOS for chart latticing.

Originally, the WARPED LATTICE PROGRAM was designed to incorporate theoretical ASF computed by Millington's Method. It has been reformatted to improve lattice accuracy by taking advantage of empirical ASF data collected from USCG and NOS surveys, which began in 1977. Figure 3 depicts the warped lattice.

ACCURATE RAPID ADDITIONAL SECONDARY PHASE FACTOR CORRECTION (ARAD) is a software system developed by Webster Research Corporation of Silver Spring, Maryland for use in the ASF Project. Figure 4 is a data flow chart.

ARAD merges the Coast Guard terrain conductivities, the hydrographic shoreline data base (SLDB) map,the Analytic Sciences Corporation (TASC), Loran-C force-fit and DMAHTC ASF determination software programs. The end product is a software system that will enable the Electronic Navigation Division to determine an ASF correction for any geographic position - worldwide.

In the TASC force-fit portion of the overall ARAD effort falls the requirement for empirical or observational data. By utilizing these data DMAHTC updates the data base that is used to produce ASF corrections. The fundamental concept of the force-fit algorithm is based on the postulation of a mathematical relationship between residual errors at known locations (monitor stations and sites) and at locations where no error information is available. This algorithm forces a fit of residual errors in a local area where data are available and then imposes this fit in neighboring areas via a distance-weighting scheme. The adjustments computed via the force-fit algorithm are added to the conductivity-derived corrections; thus the current ASF models and algorithms are not necessarily altered. Presently, the force-fit technique is being implemented using the batch processing method whereby all measurements are processed at a single time. The mathematical form and flow diagram for force-fit implementation is shown in Figure 5.

In 1977, test cases were run using data from three Loran-C chains: East Coast (9930), Southeast Asia (SEA), and Northwest Pacific (9970). Values of percentage improvement for the three chains are shown in Table 1.

TABLE I

LORAN-C ACCURACY IMPROVEMENT USING

FORCE-FIT TECHNIQUES

Chain	% Improvement
U.S. East Coast	27
SEA	71
Northwest Pacific	15

Differences in the results may vary with several factors that are a function of the calibration procedure, location of chain, time period of calibration, etc.

LORAN-C CORRECTION TABLES

TABLE DESCRIPTIONS

Each table contains a complete chain. A table section is prepared for each station pair (master station and one secondary station) in a Loran-C chain. As a rule the limits of the table coverage are determined by the range of the groundwave transmissions for the Loran-C chain. Each page of corrections in the table covers an area 3^{o} in latitude by 1^{o} of longitude, with corrections printed in increments of 5' of arc. The latitude values are printed in the left-hand column of each correction page. The longitude values are printed in the upper and lower row of the page. Rate designation and page numbers are printed at the top of each correction page.

Pages are numbered from left to right, starting in the upper left corner of the area, as shown in page index with each section of the tables. Those pages on which the latitude and longitude limits include all land will be omitted and their numbers transferred to the next appropriate page. Those pages where latitude and longitude limits contain both land and sea are included but contain corrections only for the area covered by the U.S. Coastal Conference Zone. Large land bodies and areas outside the CCZ will be represented by blank spaces on the page.

ASF correction values can be either positive or negative. Negative values are indicated by a negative sign preceding the number. The positive values are shown without sign. Areas requiring no correction show a zero value which in some cases is preceded by a negative sign. The negative sign preceding a zero results from the rounding off of a value slightly less than zero and indicates the trend of the correction.

USE OF TABLES

The ASF Correction Tables are published primarily for precision navigation, utilizing digital computers to convert Loran-C time differences to geographic coordinates. This does not preclude use of the tables with manual plotting methods.

Although the ASF Corrections are generally too small to affect a Loran-C fix plotted on a small scale chart, they can become as large as ± 4 microseconds. This offset in feet will be minimal on the baseline, but in other areas of coverage this offset is appreciable due to expansion of lane width between hyperbolas. For example, at $32^{o}00'$N. and $80^{o}00'$W, using lattice pair 9960-x, a 4 microsecond error will offset the 9960-X line of position by approximately 8000 feet.

The table can be entered directly by using the ship's position determined to the nearest 5' of arc in latitude and longitude either by dead reckoning or some other means. To find the page with the appropriate correction, the Page Indexes of the table must be utilized. These indexes show the limits and page number of all pages in the table. Enter the index with the ship's position and locate the number of the page on which the desired correction is found. In some cases the ship's position will fall on the page limit in either latitude or longitude or both. These positions are repeated on both pages and either page may be used. The ASF Correction is added algebraically to the time difference for the Loran-C pair. Many users having electronic computers will enter these values directly into the computer. While in the area where the corrections apply, the values will be applied automatically to all sampled time differences for particular pairs. The geographic position determined from the corrected time differences will provide a more precise position.

TABLE LIMITATIONS

Interpolation of these data will not necessarily improve accuracy since the information is not of a linear nature. The correction nearest the derived latitude and longitude should be applied to the appropriate time difference.

ASF Corrections should be used with caution for areas within 10 nautical miles of land. This area represents an unreliable zone where large variations occur in the magnitude of the correction.

CAUTION

This table is not to be used with a chart that provides a corrected lattice. Charts which portray corrected lattices contain one of the following notes:

> "The Loran-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are presently compensated only for theoretical propagation delays, which have not yet been verified by observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided."

or

> "The Loran-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are compensated with propagation delays computed from observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided."

EXAMPLE

Loran-C receiver dial readings sampled by the computer are 12153.31 microseconds and 44451.83 microseconds for pairs 9960-W and 9960-Y respectively. From these readings the computer determines a position of $44^{o}15.1'$N. latitude and $67^{o}25.4'$W. longitude. Entering the page Index of Section W with the latitude and longitude nearest to the computed ship's position, the page number containing the derived geographics is found to be 17 W, example page. Entering page 17 W the correction at $44^{o}15'$N and $67^{o}25'$W is 1.5 microseconds. On page 17 Y, example page, at the same position the correction is 2.7 microseconds.

The ASF corrections are applied to the dial readings as follows:

WTD	12153.31	YTD	44451.83
ASF CORRECTION	1.5	ASF CORRECTION	2.7
CORRECTED TO	12154.81	CORRECTED TO	44454.53

The corrected dial readings are used to recompute a new latitude and longitude for the Loran-C fix. The new position is 44^{o}15.4'N. latitude and 67^{o}26.4'W. Figures 6 and 7 are example pages.

NATIONAL OCEAN SURVEY (NOS) WEST COAST SURVEY

In 1977, to verify predicted lattices derived from the Warped Lattice and ARAD Programs, the USCG and NOS began surveys in critical areas of the CCZ. The following surveys have been completed:

Chain	Rate
Northeast - 9960	
Southeast - 7980	
Great Lakes - 8970,9960	
West Coast - 9940	
Straits of Juan de Fuca - 9940	

The West Coast Survey, which represents the procedures used, is discussed here:

In the summer of 1977, during field tests of the Loran-C chain 9940, the U.S. Coast Guard discovered apparent differences between predicted and observed Loran-C values in the offshore area between Point Arguello and San Diego. The errors, in the south-southwest direction, appeared to be 1 mile in the Santa Barbara area; 1½ miles in the Los Angeles area; and 2 miles in the San Diego area. The charts involved were: 18720, 18740, 18721, 18746, 18765. Figure 8 shows the area and charts.

Because of the heavy volume of vessel traffic in this area, the Coast Guard through NOS, requested the NOAA Ship Rainier to run a series of tracks taking simultaneous Raydist/Mini-Ranger geographical positions (GP) and Loran-C time differences (TD), using Loran-C pairs 9940-X and 9940-Y. In addition, upon completion of the survey the Coast Guard requested that the Rainier forward the collected data to the Electronic Navigation Division, DMAHTC, for analysis and evaluation. The formats were a computer printout of the Raydist/Mini-Ranger GP's and Loran-C receiver TD's (figure 9) and a track chart with numbered fix points corresponding to each reading on the computer printout. There were 1600 fix points. Figure 10 is a small scale version of the track chart. In the area covered by the above listed charts the USCG's primary concern was to insure traffic separation in the shipping lanes. The survey data proved to be more accurate than the theoretical predictions. Consequently, these data were used to provide ¼ NM accuracy.

CONCLUSION

As mentioned previously, the Warped Lattice Program and ARAD through the TASC force-fit software program incorporate empirical Loran-C observations to improve predicted Loran-C lattices. Consequently, DMAHTC and the USCG need to collect Loran-C comparisons from as many sources as possible. Figure 11 shows the DMAHTC Calibration Questionnaire, which is included in the weekly Notice to Mariners. Additionally, the USCG and NOS will continue their Loran-C comparison surveys in the CCZ and Great Lakes. For 1981, at least three surveys are planned.

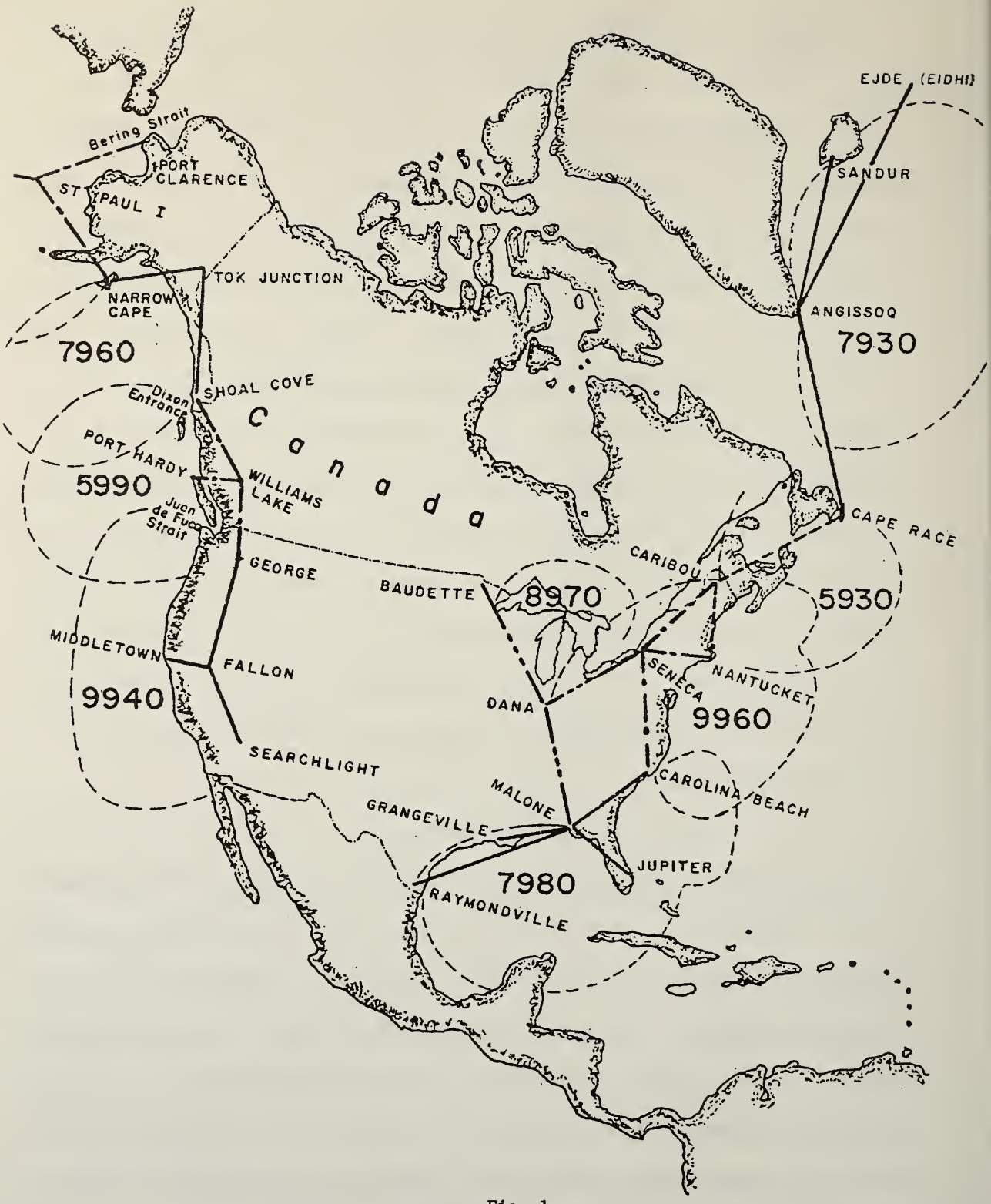
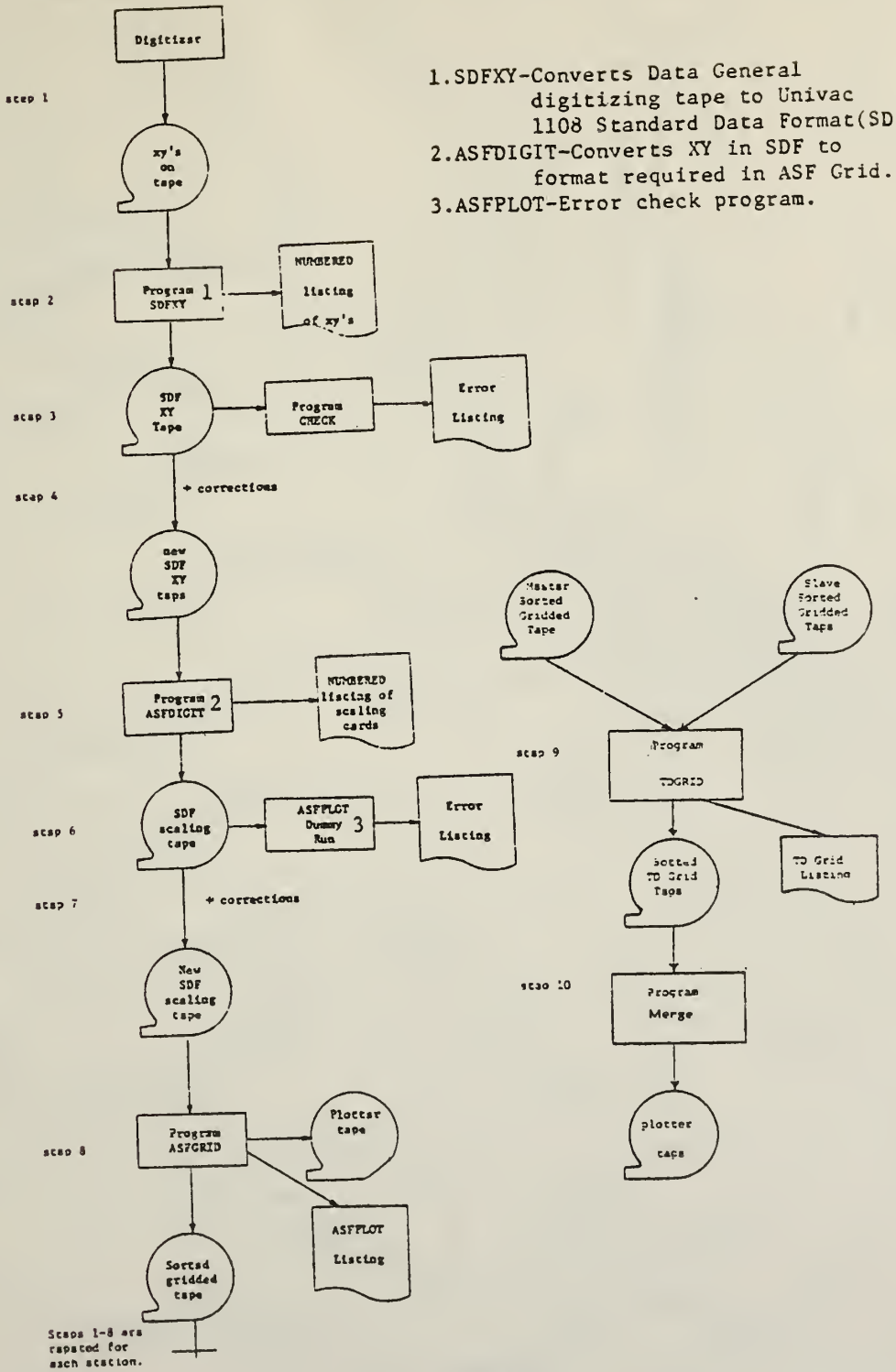


Fig. 1

Chain Coverage In The United States and Canada



1. SDFXY-Converts Data General digitizing tape to Univac 1108 Standard Data Format(SDF).
2. ASFDIGIT-Converts XY in SDF to format required in ASF Grid.
3. ASFPLOT-Error check program.

Fig. 2

Warped Lattice Flow Diagram

Fig. 3 Warped Lattice Chart

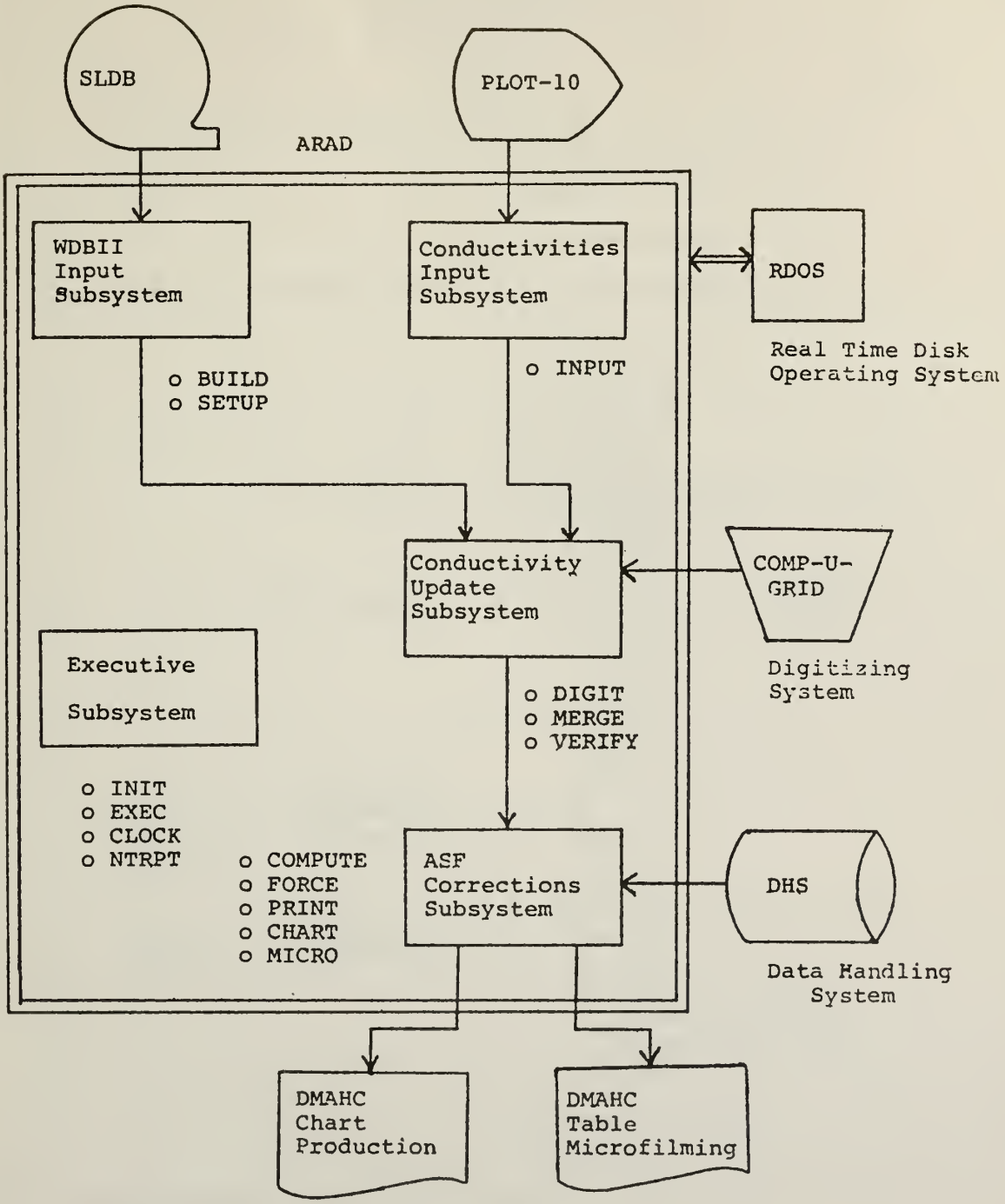


Fig. 4 ARAD System Data Flow

$$\hat{\underline{x}} = MH^T(HMH^T)^{-1}\,\underline{z}$$

where

$\hat{\underline{x}}$ is the optimal estimate of residual Loran-C errors

M is the error covariance matrix

H is the measurement matrix

$\underline{z}$ is the measurement vector (known residual error)

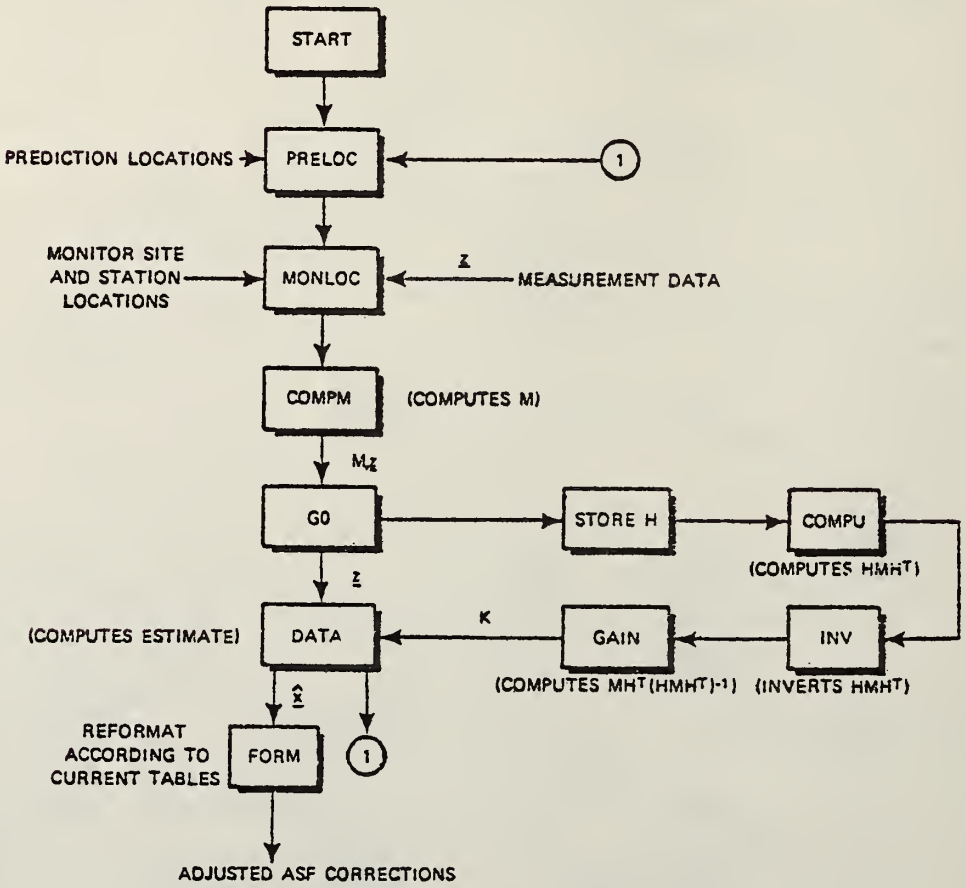


Fig. 5 Flow Diagram for Force-Fit Implementation

DATE 1114

9960-W 17W

LONGITUDE WEST

LATITUDE NORTH	68 0	55	50	45	40	35	30	25	20	15	10	5	67 0
45 0													
55													
50													
45													2.0
40												1.7	1.6
35									1.7	1.7	1.6	1.6	1.6
30							1.7	1.6	1.6	1.6	1.5	1.5	1.5
25					1.6	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5
20	1.6	1.5	1.6	1.6	1.5	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5
15	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4
10	1.5	1.4	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3
5	1.4	1.4	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	
44 0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.3	1.3			
55	1.3	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.2				
50	1.3	1.3	1.3	1.3	1.3	1.3	1.3						
45	1.3	1.3	1.2	1.3	1.3	1.3							
40	1.2	1.2	1.3	1.3	1.3								
35	1.3	1.2	1.3										
30	1.3	1.3	1.3										
25	1.2	1.3	1.3										
20	1.2	1.3	1.3	1.3									
15	1.2	1.3	1.3	1.3	1.3								
10	1.2	1.2	1.3	1.3	1.3								
5	1.2	1.2	1.2	1.3	1.3	1.3							
43 0	1.2	1.2	1.2	1.2	1.3	1.3	1.3						
55	1.2	1.2	1.2	1.2	1.3	1.3	1.3						
50	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3					
45	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3				
40	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3			
35	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3			
30	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3			
25	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.3
20	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.3
15	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.2
10	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.3	1.2
5	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
42 0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	68 0	55	50	45	40	35	30	25	20	15	10	5	67 0

LONGITUDE WEST

Fig. 6

Example pages

LE 9960-Y DATE 11218C

9960-Y 17Y

LONGITUDE WEST

LATITUDE NORTH	68 0	55	50	45	40	35	30	25	20	15	10	5	67 0
45 0													
55													
50													
45													3.4
40												3.1	3.0
35									3.0	3.1	3.0	2.9	2.9
30							2.9	2.9	2.9	2.9	2.8	2.8	2.8
25					2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.7	2.7
20	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.6	2.7	2.6
15	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.7	2.7	2.6	2.6	2.6	2.6
10	2.7	2.6	2.6	2.7	2.7	2.6	2.6	2.5	2.5	2.6	2.6	2.6	2.6
5	2.6	2.6	2.6	2.6	2.5	2.5	2.4	2.4	2.4	2.5	2.5	2.5	
44 0	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.3	2.4	2.4			
55	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4				
50	2.4	2.4	2.4	2.4	2.4	2.4	2.4						
45	2.4	2.4	2.3	2.4	2.4	2.4							
40	2.3	2.3	2.3	2.4	2.4								
35	2.4	2.4	2.4										
30	2.4	2.4	2.4										
25	2.4	2.4	2.4										
20	2.4	2.4	2.4	2.4									
15	2.4	2.4	2.4	2.4	2.4								
10	2.4	2.4	2.4	2.4	2.4								
5	2.4	2.4	2.4	2.4	2.4	2.4	2.4						
43 0	2.4	2.4	2.4	2.4	2.4	2.4	2.4						
55	2.4	2.4	2.4	2.4	2.4	2.4	2.4						
50	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4					
45	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4				
40	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4			
35	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4			
30	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4			
25	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.5
20	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
15	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
10	2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
5	2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
42 0	2.4	2.3	2.3	2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	69 0	55	50	45	40	35	30	25	20	15	10	5	67 0

LONGITUDE WEST

Fig. 7

Example pages

LE 9960-Y DATE 11218C

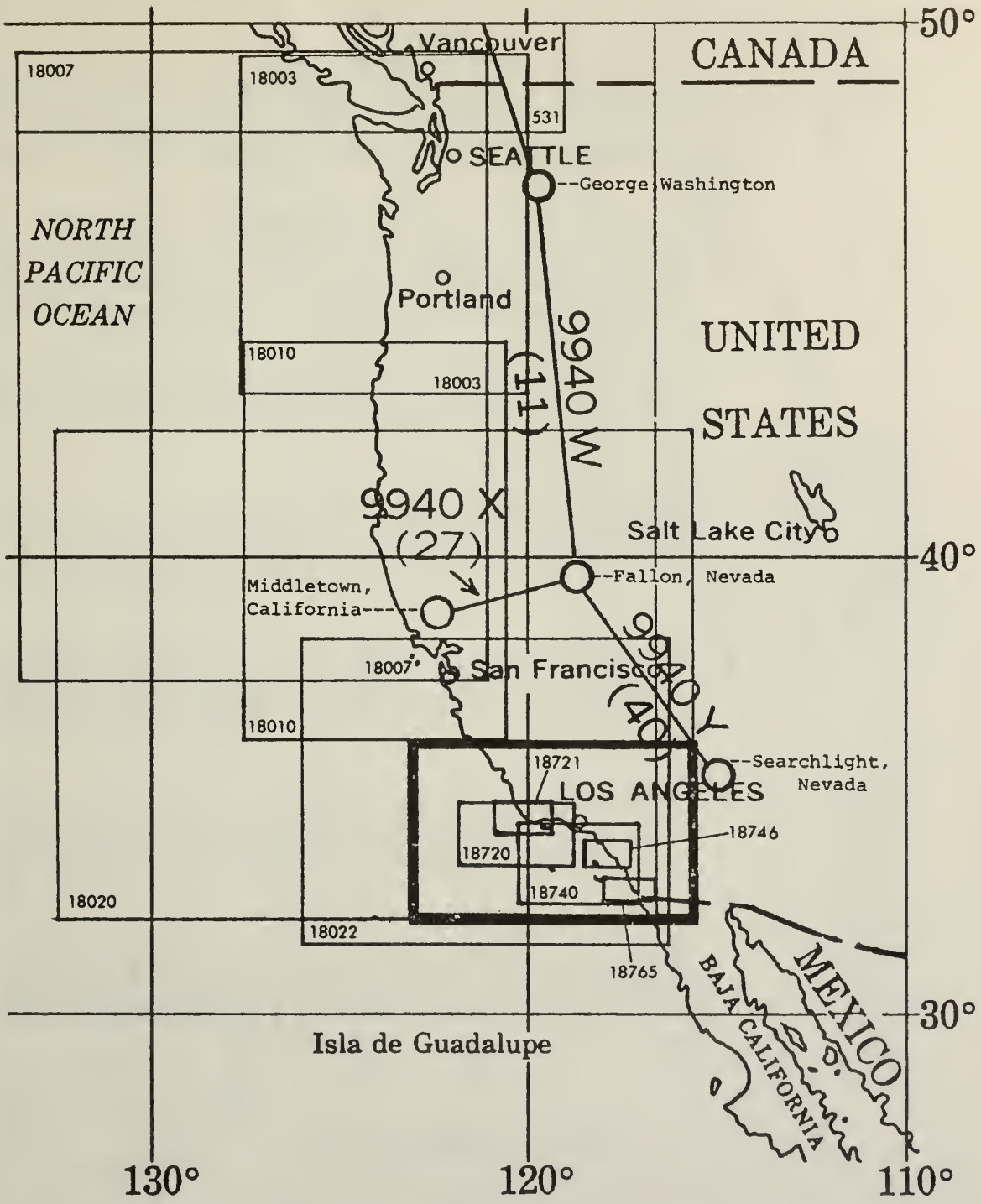


Fig. 8 Empirical Study Chart Coverage

NOAA SHIP RAINIER
ADVANCE INFORMATION
SUBJECT TO OFFICE REVIEW

SP-PMC-6-RA-77
LORAN-C COMPARISON
SOUTHERN CALIFORNIA
SEPT. 25 - OCT. 6, 1977
NOAA SHIP RAINIER
JAMES P. RANDALL, CAPT., NOAA
COMMANDING

J.D.	TIME	LORAN-C RATES RECEIVER 1		RECEIVER 2		RAYDIST/MINI-RANGER POSITION LATITUDE N	LONGITUDE W
268	215100	277925	419354	277923	419353	34 44 04.2	120 49 55.7
	215400	277926	419351	277926	419349	34 44 02.4	120 49 53.8
	215700	277927	419352	277925	419352	34 44 03.4	120 49 53.7
	220000	277926	419354	277926	419353	34 44 05.9	120 49 53.5
	220300	277942	419343	277939	419340	34 44 10.1	120 49 24.5
	220600	277964	419317	277965	419315	34 44 14.7	120 48 37.9
	220900	277981	419288	277978	419288	34 44 01.7	120 48 07.0
	221200	277997	419266	277997	419265	34 43 56.8	120 47 34.0
	221500	278003	419234	278002	419232	34 43 27.1	120 47 20.7
10 →	221800	278011	419200	278010	419198	34 42 57.5	120 47 05.1
	222100	278018	419168	278017	419166	34 42 28.1	120 46 51.2
	222400	278025	419137	278024	419136	34 41 59.2	120 46 37.6
	222700	278032	419103	278032	419102	34 41 30.0	120 46 23.8
	223000	278038	419072	278038	419071	34 41 00.9	120 46 10.1
	223300	278045	419040	278043	419039	34 40 31.6	120 45 56.5
	223600	278052	419009	278051	419007	34 40 02.1	120 45 42.7
	223900	278060	418974	278058	418974	34 39 32.8	120 45 27.9
	224200	278068	418943	278065	418942	34 39 03.7	120 45 13.9
	224500	278073	418911	278073	418910	34 38 34.9	120 45 00.5
20 →	224800	278079	418879	278079	418877	34 38 06.3	120 44 46.6
	225100	278087	418846	278085	418846	34 37 37.7	120 44 32.7
	225400	278093	418816	278092	418814	34 37 08.5	120 44 18.6
	225700	278100	418784	278099	418782	34 36 38.7	120 44 04.8
	230000	278106	418750	278106	418748	34 36 08.5	120 43 51.5
	230300	278114	418717	278110	418717	34 35 38.0	120 43 36.6
	230600	278119	418685	278118	418684	34 35 08.2	120 43 22.8
	230900	278126	418653	278124	418652	34 34 38.7	120 43 09.2
28 →	231200	278133	418621	278132	418621	34 34 09.8	120 42 55.1
33 →	233000	278207	418540	278206	418539	34 34 17.1	120 40 30.4
	233300	278196	418577	278195	418575	34 34 45.5	120 40 51.5
	233600	278189	418612	278188	418610	34 35 17.1	120 41 06.3
	233900	278184	418645	278182	418644	34 35 48.8	120 41 20.6
	234200	278177	418678	278176	418678	34 36 20.9	120 41 34.4

Fig. 9 Computer Printout

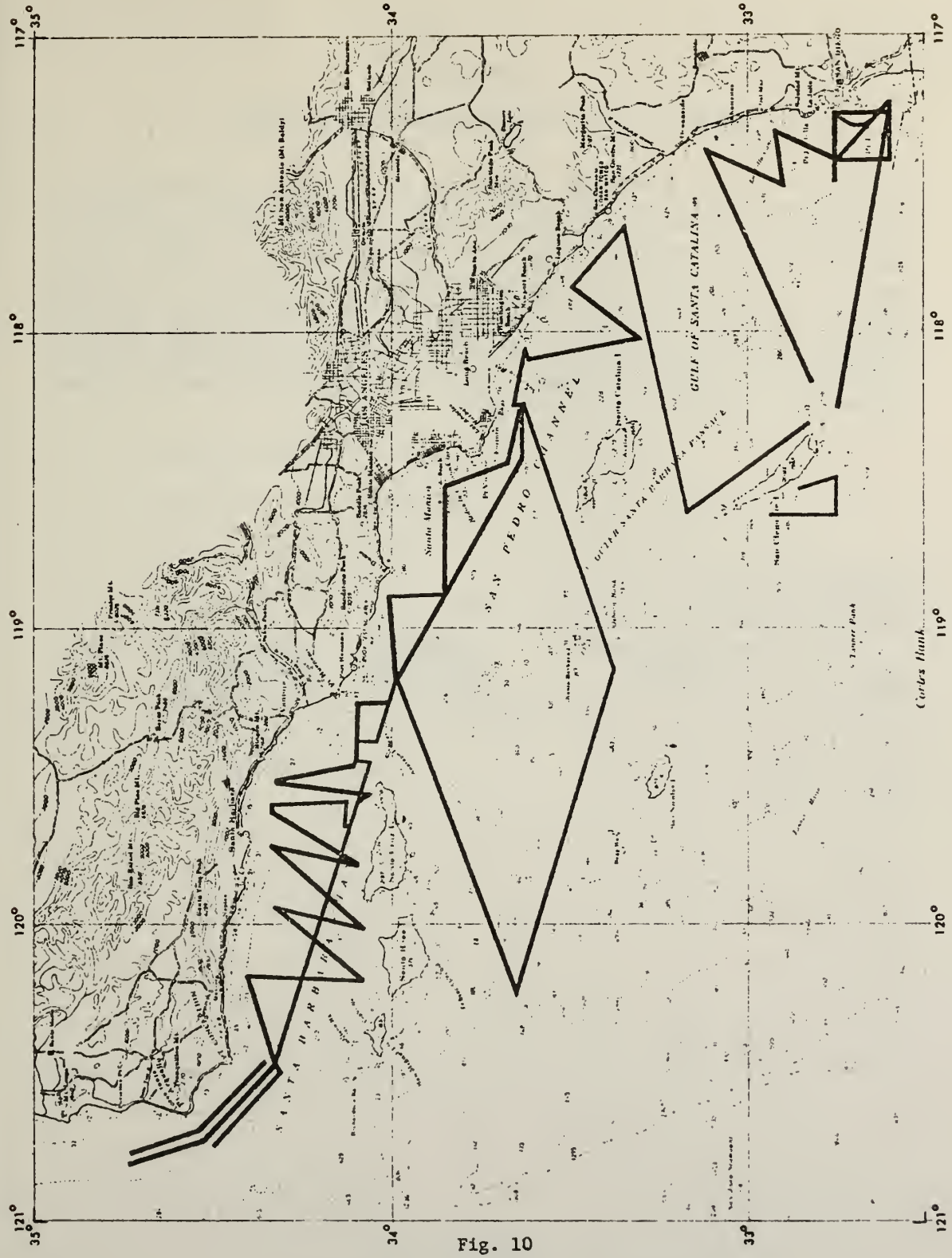


Fig. 10
Small-scale version of track chart

SECTION III

DMAHTC LORAN-C CHART CALIBRATION QUESTIONNAIRE

Calibration information is being collected in an effort to evaluate and improve the accuracy of the DMAHTC derived LORAN signal propagation corrections incorporated in National Ocean Survey Coastal LORAN-C charts. LORAN-C monitor data consisting of receiver readings with corresponding well defined reference positions are required. Mariners aboard vessels equipped with LORAN-C receiving units and having precise positioning capability independent of the LORAN-C system (i.e., docked locations or visual bearings, radar, navigation satellite, Raydist, etc.) are requested to provide monitor information via the questionnaire found at the back of this Notice to Mariners. Please mail this questionnaire to Defense Mapping Agency Hydrographic/Topographic Center, Washington, D.C. 20315. Attention Code NVE.

VESSEL NAME _____

LORAN-C RECEIVER MAKE AND MODEL _____

OBSERVER _____

GMT	DAY OF YEAR	YR.	LORAN-C TIME DELAY READINGS (XXXXX.XX Usec.) Rate Designations (xxxx)-W	(xxxx)-X	(xxxx)-Y	(xxxx)-Z	REFERENCE POSITION (Ref. Posit. must coincide with time of TD Reading) LATITUDE XX°-XX.X′ N/S	LONGITUDE XXX°-XX.X′ E/W	REFERENCE POSITION SOURCE DESCRIPTION (i.e., Visual Bearings, Radar, Navigation satellite, Raydist, etc. or Pier location, number, & berth desig.)

Fig. 11

APPENDIXES

GRAPHICS OF INDIVIDUAL CHAIN COVERAGE IN THE CCZ AND GREAT LAKES

A. CANADIAN EAST COAST CHAIN 5930

B. NORTHEAST U.S. CHAIN 9960

C. GREAT LAKE CHAIN 8970

D. SOUTHEAST U.S. CHAIN 7980

E. WEST COAST CHAIN 9940

F. CANADIAN WEST COAST CHAIN 5990

G. GULF OF ALASKA 7960

LORAN-C

CANADIAN EAST COAST CHAIN

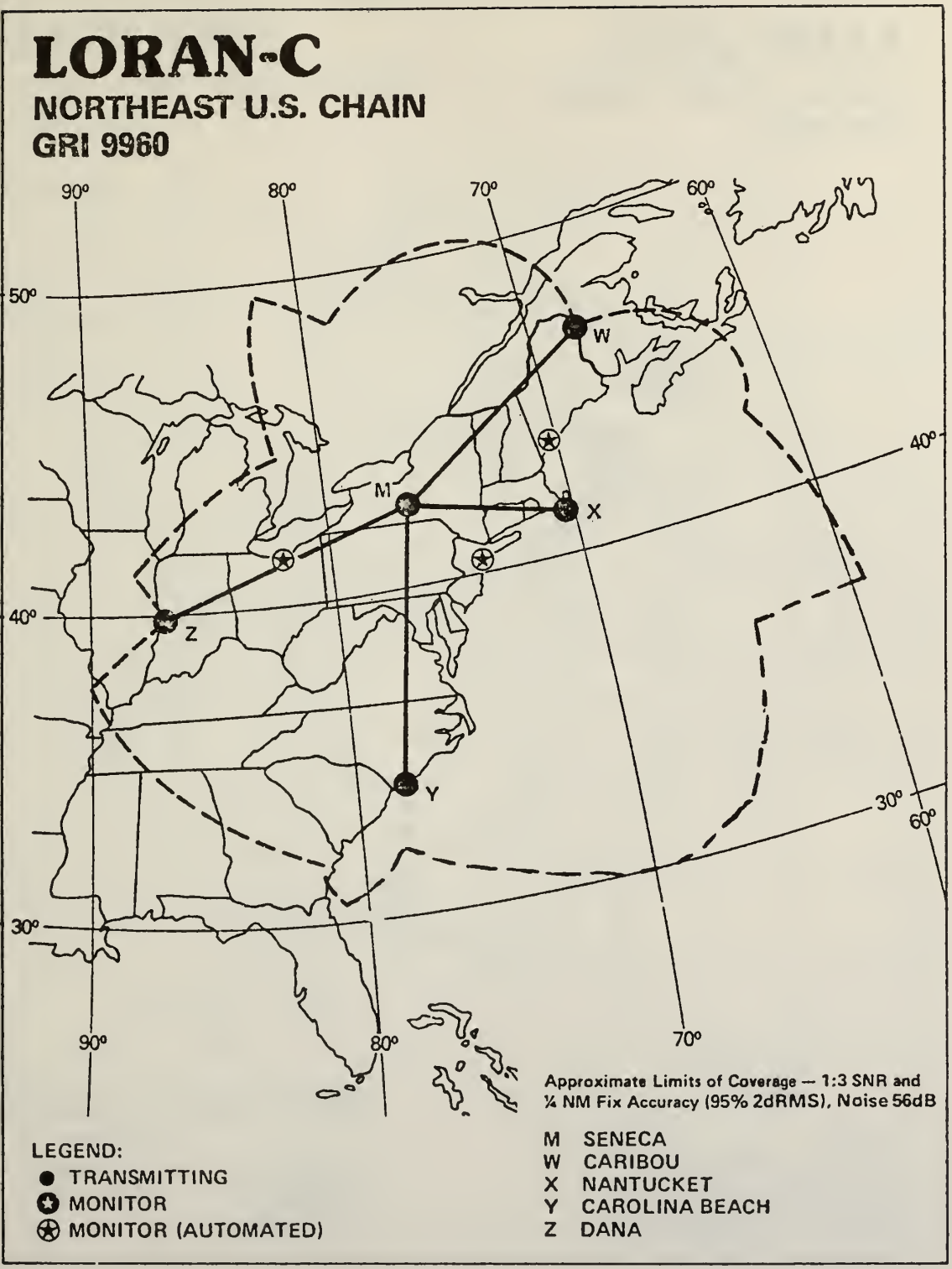
GRI 5930

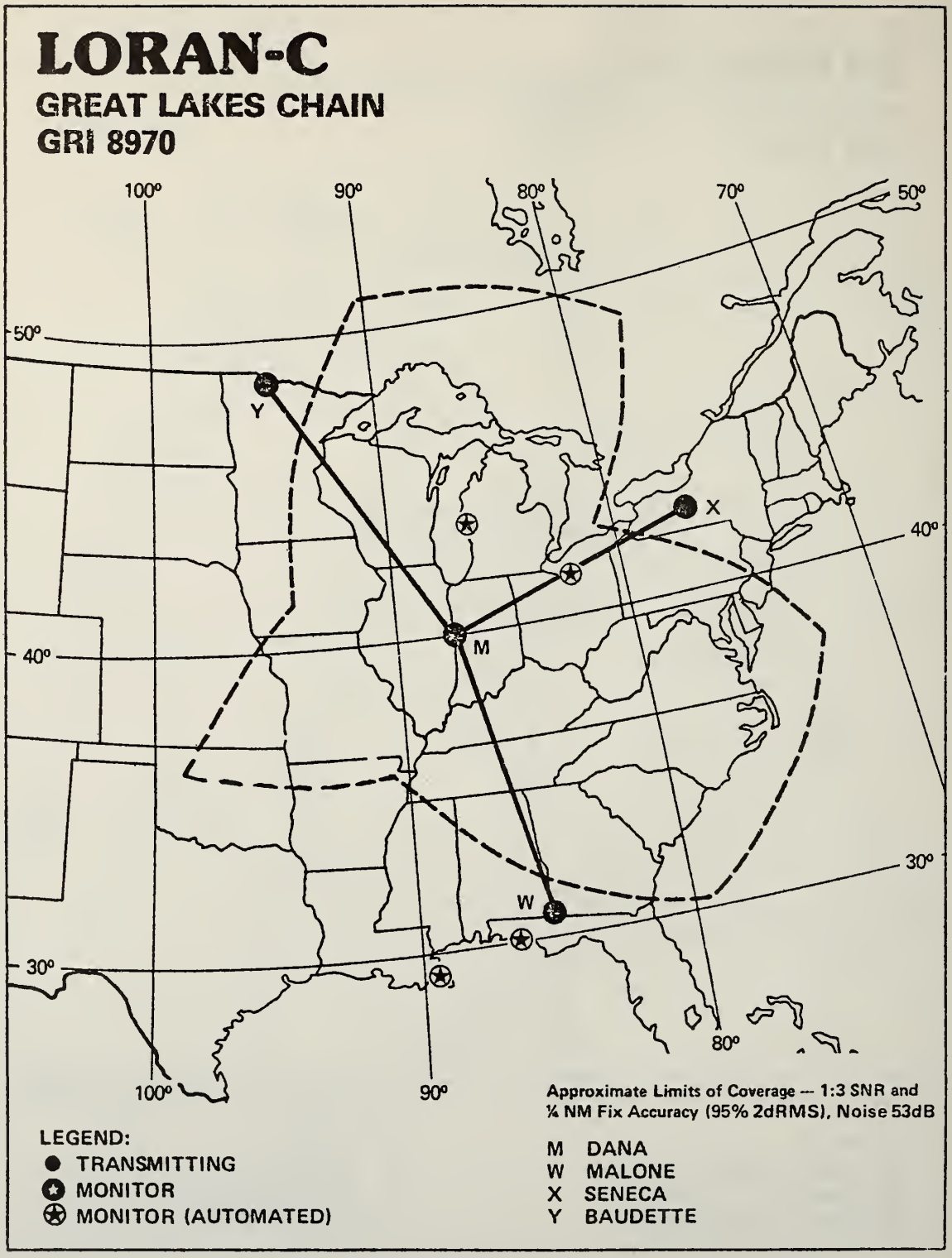
Approximate Limits of Coverage---1:3 SNR and ¼ NM Fix Accuracy (95% 2dRMS), Noise 50dB

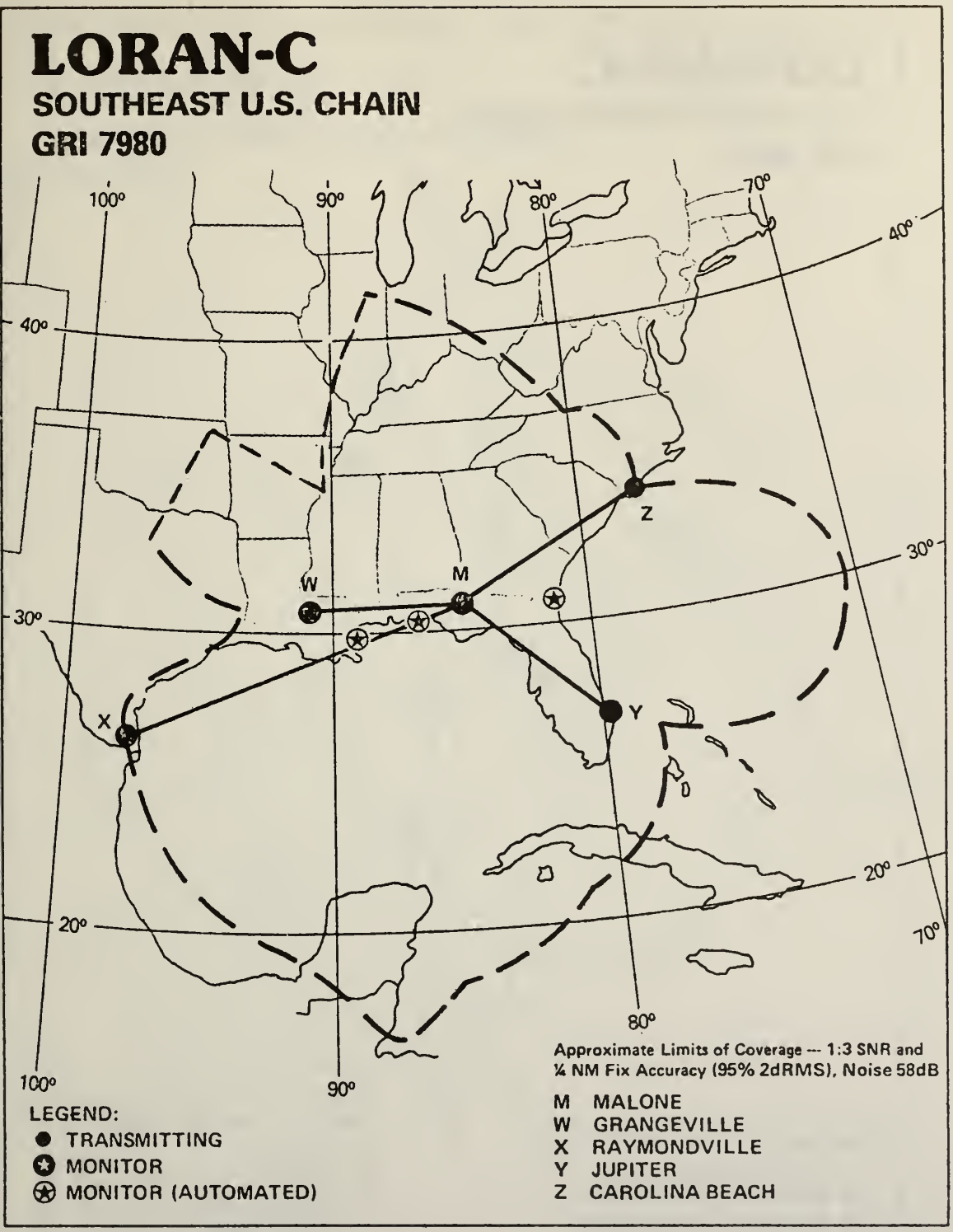
LEGEND:

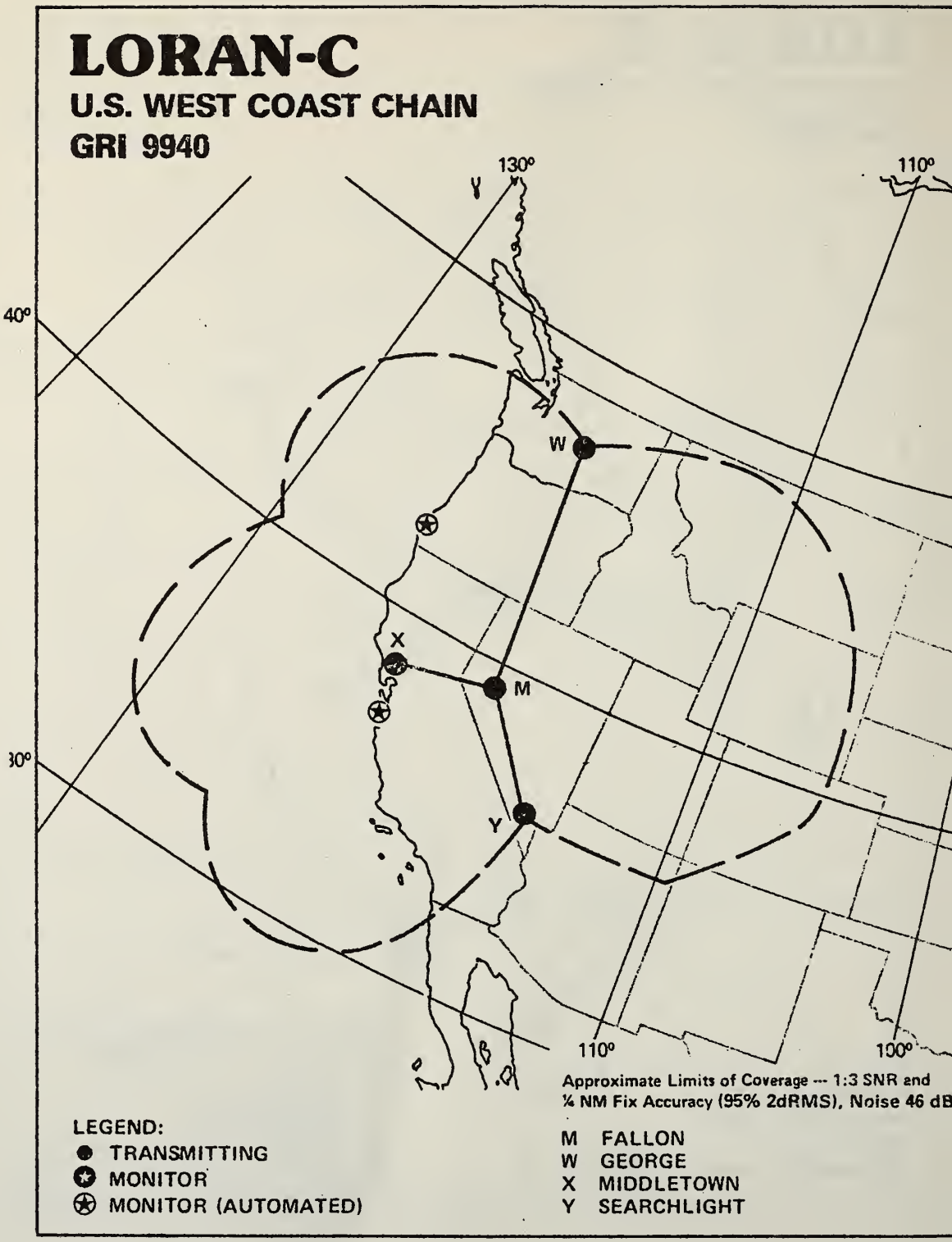
- ● TRANSMITTING
- ✪ MONITOR
- ✪ MONITOR (AUTOMATED)

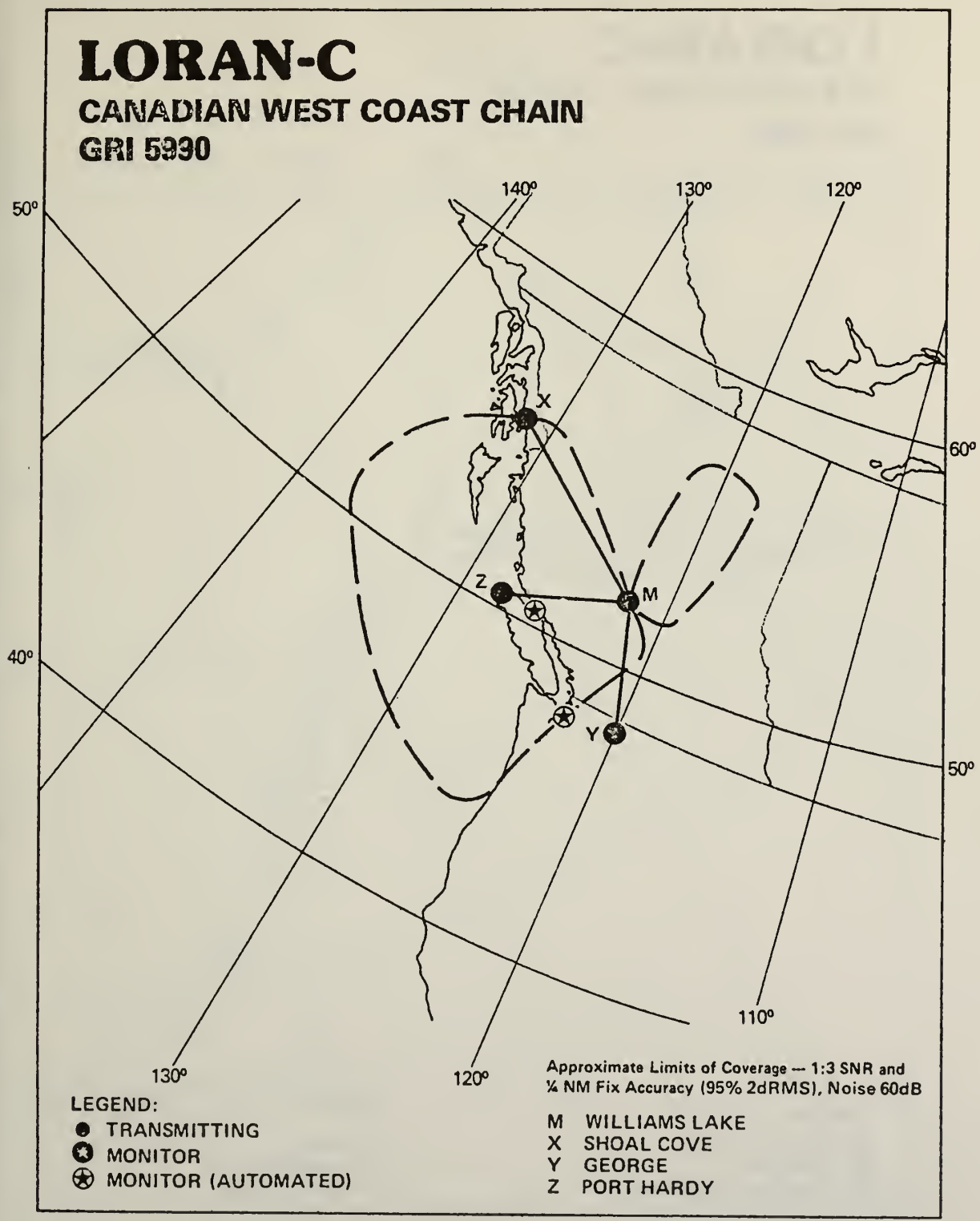
M CARIBOU
X NANTUCKET
Y CAPE RACE

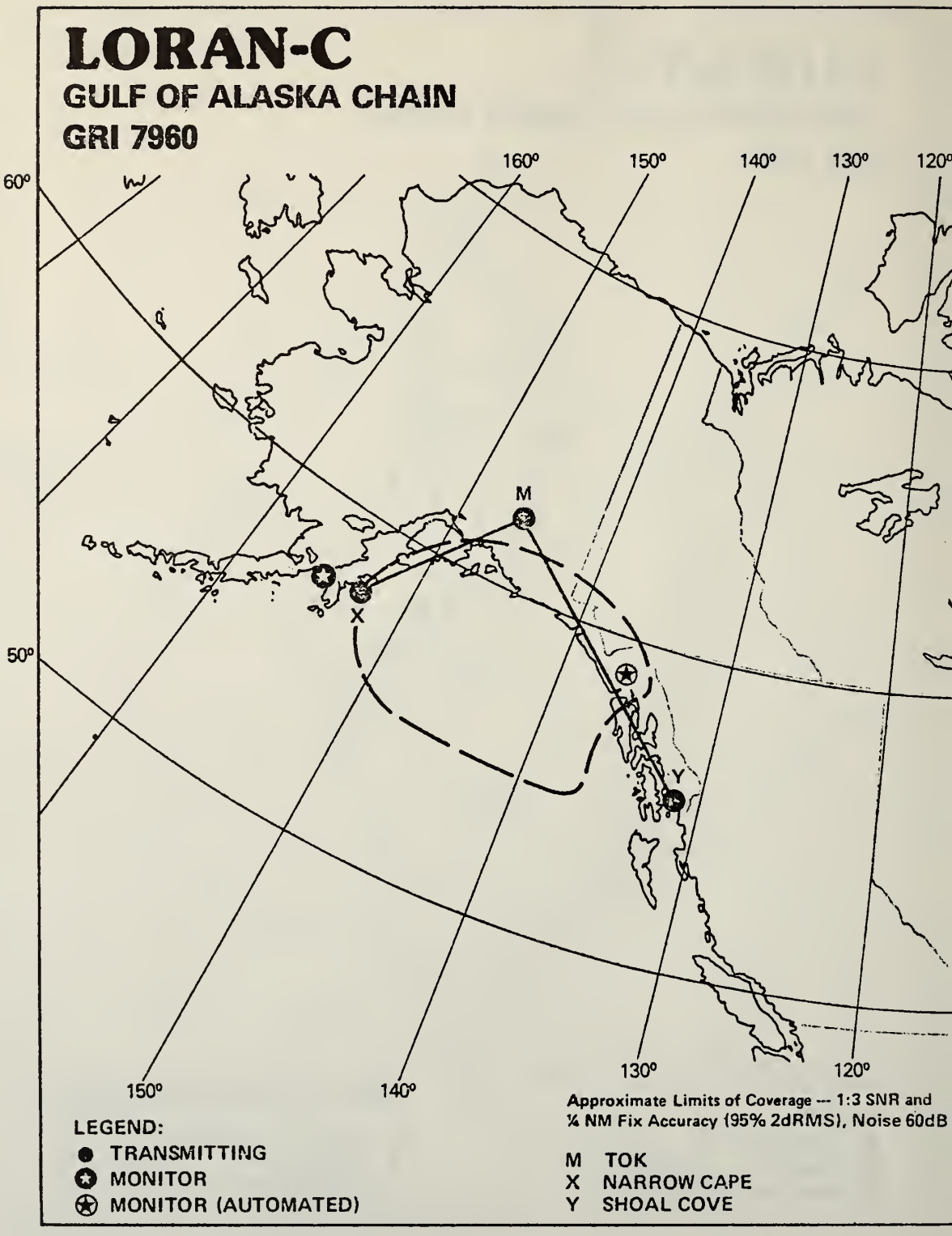

LORAN-C
NORTHEAST U.S. CHAIN
GRI 9960
90°
80°
70°
60°
50°
40°
30°
M
W
X
Y
Z
Approximate Limits of Coverage — 1:3 SNR and ¼ NM Fix Accuracy (95% 2dRMS), Noise 56dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M SENECA
W CARIBOU
X NANTUCKET
Y CAROLINA BEACH
Z DANA


LORAN-C
GREAT LAKES CHAIN
GRI 8970
100°
90°
80°
70°
50°
50°
40°
40°
30°
30°
Y
X
M
W
Approximate Limits of Coverage — 1:3 SNR and
¼ NM Fix Accuracy (95% 2dRMS), Noise 53dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M DANA
W MALONE
X SENECA
Y BAUDETTE


LORAN-C
SOUTHEAST U.S. CHAIN
GRI 7980
100°
90°
80°
70°
40°
30°
20°
W
M
Z
X
Y
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
Approximate Limits of Coverage --- 1:3 SNR and
¼ NM Fix Accuracy (95% 2dRMS), Noise 58dB
M MALONE
W GRANGEVILLE
X RAYMONDVILLE
Y JUPITER
Z CAROLINA BEACH


LORAN-C
U.S. WEST COAST CHAIN
GRI 9940
130°
110°
40°
30°
W
X
M
Y
110°
100°
Approximate Limits of Coverage --- 1:3 SNR and
¼ NM Fix Accuracy (95% 2dRMS), Noise 46 dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M FALLON
W GEORGE
X MIDDLETOWN
Y SEARCHLIGHT


LORAN-C
CANADIAN WEST COAST CHAIN
GRI 5930
140°
130°
120°
50°
60°
40°
50°
110°
130°
120°
X
Z
M
Y
Approximate Limits of Coverage — 1:3 SNR and
¼ NM Fix Accuracy (95% 2dRMS), Noise 60dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M WILLIAMS LAKE
X SHOAL COVE
Y GEORGE
Z PORT HARDY


LORAN-C
GULF OF ALASKA CHAIN
GRI 7960
60°
50°
160°
150°
140°
130°
120°
M
X
Y
Approximate Limits of Coverage --- 1:3 SNR and
¼ NM Fix Accuracy (95% 2dRMS), Noise 60dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M TOK
X NARROW CAPE
Y SHOAL COVE

MR. SPEIGHT: Thank you very much.

DISCUSSION

CAPT TRAUSCHKE: Any questions?

Admiral Houlder, I didn't put John up to putting in a plug to get a satellite receiver for the MITCHELL. Just remember that. No questions. Thank you.

Hydrographic Airborne Laser Sounder (HALS)

Duane Bright

Naval Ocean R&D Activity

NSTL Station, Miss. 39529

January 1981

ABSTRACT

The Defense Mapping Agency has tasked the Naval Ocean Research and Development Activity (NORDA) to develop the Hydrographic Airborne Laser Sounder (HALS) to support a long-standing requirement for faster and cheaper ways to conduct hydrographic surveys in shallow nearshore waters. The HALS consists of a scanning laser sounder and altimeter, orientation equipment, a data processor and recorder, and electronic positioning equipment. It is intended to be installed and used in the helicopter carried by the Naval Oceanographic Office's hydrographic survey ship. It will collect and record data from which accurate water depths and their geographic positions can be resolved. Using green light pulses, the HALS will measure depths to 20 meters during daylight in coastal waters of typical mid-latitude clarity. At an altitude of 150 meters and a speed of 70 knots, it will cover 8,000 square meters per second with a density of one sounding every 20 square meters. System specifications were developed and a contract was negotiated with an industrial firm. Training, manuals, transport cases, and software documentation will be provided by the contractor. NORDA expects to complete this development of the HALS in 1982.

INTRODUCTION

The Defense Mapping Agency (DMA) has a continuous requirement from the Navy to conduct hydrographic surveys along coastlines throughout the world. These surveys are now accomplished by soundboats equipped with acoustic echo sounders. Problems such as flow noise and cavitation limit survey speeds to 30 knots at best, and in hazardous nearshore waters, boat speeds may be as slow as 2 or 3 knots. Thus, hydrographic surveying in shallow waters is slow and expensive.

The Naval Ocean Research and Development Activity (NORDA), under the sponsorship of DMA, is developing an airborne laser system for the Naval Oceanographic Office (NAVOCEANO). Figure 1 illustrates the objective, which is to reduce the cost of hydrographic surveying by surveying at aircraft speeds. This system, the Hydrographic Airborne Laser Sounder (HALS), will collect soundings from the helicopter carried by NAVOCEANO hydrographic survey ships. The HALS will fly over the area to be surveyed, scan the area underneath, and record a pattern of soundings from the shore out to as deep as the system can penetrate. This depth depends on water clarity; and in typical mid-latitude coastal waters, during daylight, 20 meters may be the limit. The area beyond this depth will still have to be surveyed by soundboats, but the area will be defined and the boats will not be limited to the slow speeds required for hazardous shallow waters. The horizontal positions of the HALS soundings can be obtained by the same shore-based electronic positioning system used for the soundboats.

This paper describes the approach taken, how specifications were developed for a fieldworthy system, and where we are in the program.

GENERAL

The HALS laser depth sounder consists of a pulsed laser, a receiver, and a signal processor. As shown in Figure 2, the laser transmits a short, powerful green light pulse into the water. About 2% of the light is reflected from the surface and is detected by the receiver. Some is scattered in the water and comes back to the receiver. Finally, if the water isn't too deep or too turbid, some of the light reflects from the bottom back to the receiver. The resultant signal from the photomultiplier in the receiver will typically show a strong surface return, a diminishing backscatter,

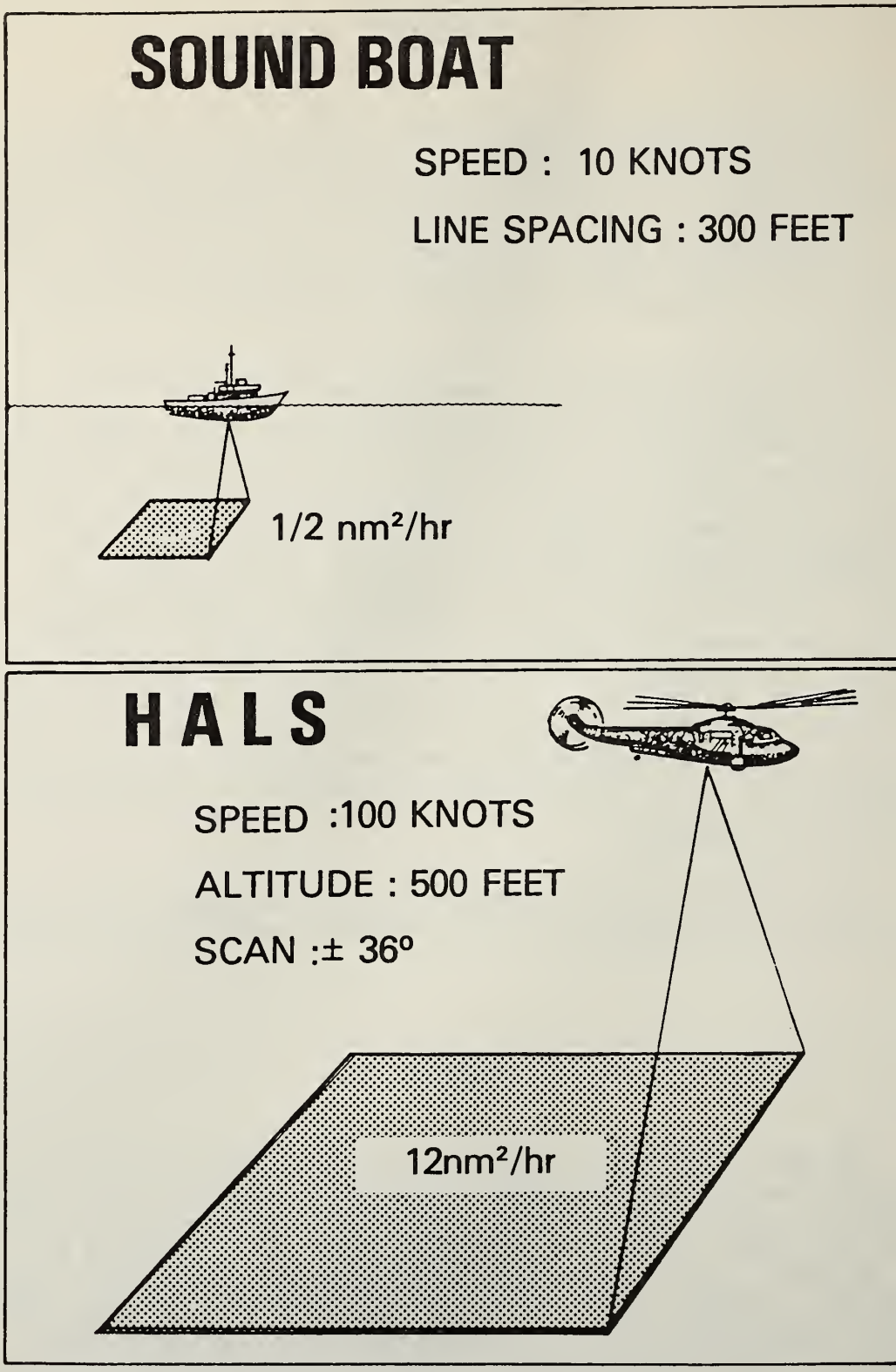


Figure 1. Airborne laser system

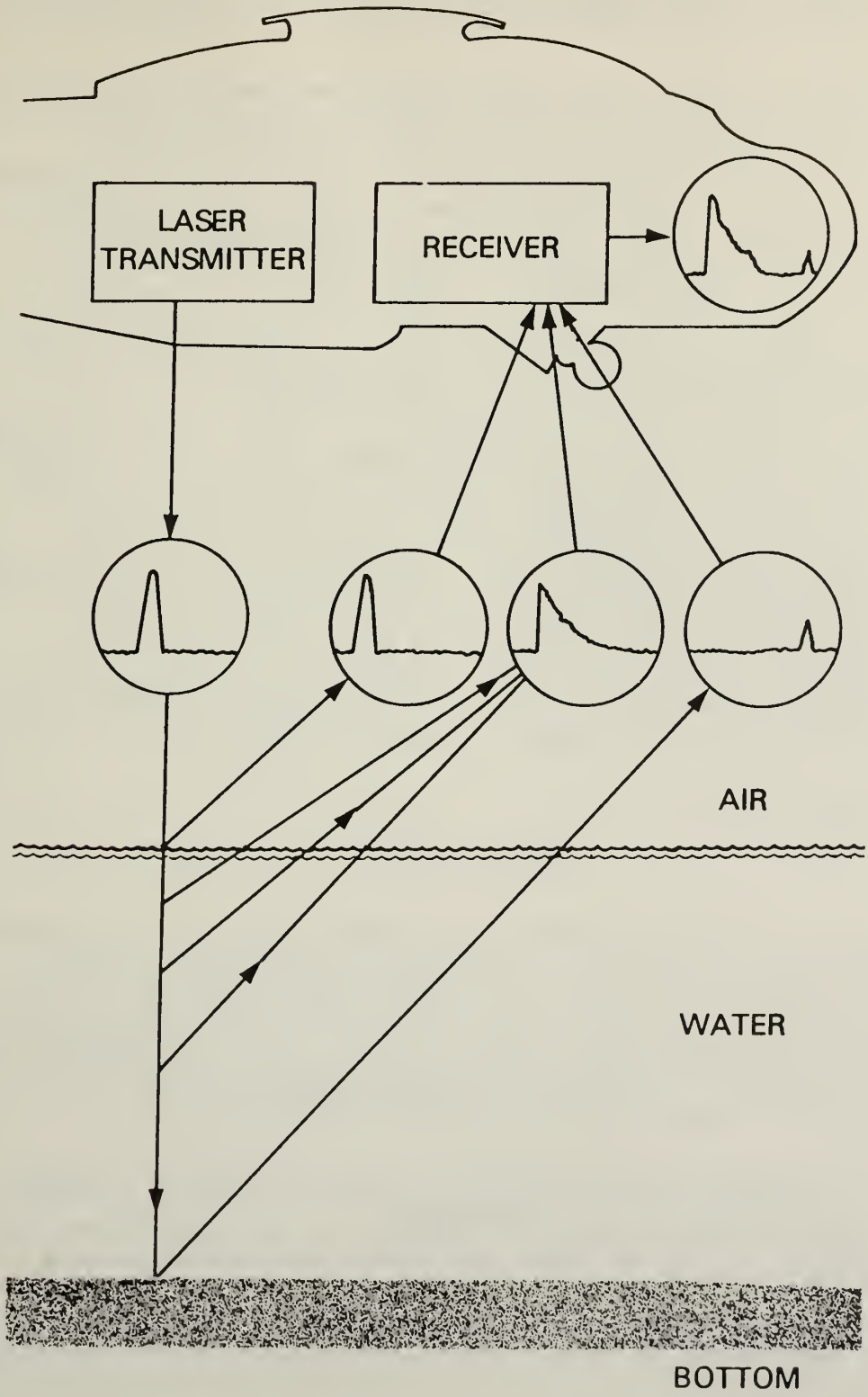


Figure 2. Laser transmitting light pulse into water

and a final pulse that drops off to the noise level. The time between receipt of the surface and bottom pulses is proportional to water depth.

A number of laser depth sounders have been developed and tested. In 1968, Dr. D. Hickman, then with Syracuse University Research Corporation, demonstrated the first airborne system over Lake Ontario {1}. Also in 1968, the Naval Oceanographic Office (NAVOCEANO) developed a YAG laser and measured depths to 100 feet in 1969 with a system called the Pulsed Light Airborne Depth Sounder (PLADS). In 1971, the Naval Air Development Center (NADC) demonstrated the feasibility of scanning with such a system. They also measured to greater depths under controlled conditions (water quality measurements) and developed formulas for predicting system performance {2}. In 1974, the National Aeronautics and Space Administration, under agreement with the U. S. Naval Oceanographic Office, tested a system designed by the Navy called the Coastal Aerial Photo-Laser Survey (CAPS) {3} System which combined an aerial mapping camera, a profiling laser, and a positioning system. In 1976, NASA developed a system called the Airborne Oceanographic Lidar (AOL) {4} with financial assistance from the DMA/NAVOCEANO. It's hydrographic surveying capabilities were tested to Navy's test plan in 1977 with assistance from NORDA, and National Ocean Survey (NOS). This system was able to make and record accurate soundings to a depth of 10 meters at a rate of 400 Hz while scanning out to 15^{o} from the vertical. The Canada Centre for Remote Sensing {5} and the Defence Research Centre of Australia {6} are also working on laser bathymetry.

SPECIFICATIONS

By 1978, the Navy decided that a reliable scanning laser sounder could be built for field use. Preparations were made to develop an advanced development model suitable for operational use. Utilizing knowledge gained through our feasibility tests and assessment of state-of-the-art technology, a purchase description was prepared {7}, and a contract was negotiated in September 1979. The specifications of Figures 3, 4, and 5 are from that purchase description.

The depth penetration capability of KD = 3.2 (Figure 3) means that in waters with a diffuse attenuation (K) of $0.16m^{-1}$, the HALS must be able to measure depth to 20 meters. K is a coefficient of water clarity. It is the amount of attenuation experienced by a diffuse field of monochromatic light traversing a fixed distance in water. In other words, its inverse, $\frac{1}{K}$, is the distance within which diffuse light decays by a factor of e, the base of natural logarithms.

HALS SPECIFICATIONS

Depth	KD = 3.2
	50m Maximum
	1/2m Minimum
Accuracy	$\pm$.28m at <20m
	$\pm$1m at >20m
Area Coverage	28.8 km^2/hour (8.4 n. $mi.^2$/hour)
Data Density	Every $20m^2$
	50,000/km^2
Positioning	Med. Range Electronic
Scan Angles	0 to $\pm$ 624 mrad (0 to $\pm$ 36°)
Roll & Pitch Accuracy	$\pm$20 mrad ($\pm$1.15°)
Heading Accuracy	$\pm$40 mrad ($\pm$2.29°)
Altitude Range	100 to 800m (328 to 2,625 ft.)
Altitude Accuracy	$\pm$.1m or .05%
Installation	6 hours (2 men)
Ease of Operation	One Operator
Safety	Eye Safe at 150m (ANSI Z136)
Mission Time	2 Hours

Figure 3

The maximum of 50 meters (Figure 3) insures that the system will be able to handle and record such a depth on those occasions when the water is extremely clear. In typical mid-latitude coastal waters, a "power factor" of KD = 3.2 will enable the HALS to survey out to about a depth of 20 meters. The minimum of 1/2 meter, rather than zero, is due to the difficulty of differentiating between the surface and bottom return pulses at very shallow depths.

During the NASA/NORDA/NOS testing of the Airborne Oceanographic Lidar, attenuation measurements of the water were made to verify the power formula being used. NADC has also continued to conduct tests with their advanced equipment utilizing their prediction formula under a variety of field conditions. Other formulas are also available {3}, {4}, and {8}. The following is a simplified example:

$$P_R = P_T \, T_I^2 R \, \frac{A}{(D+H)^2} \, e^{-2KD}$$

where

P_R = Power of signal received by the system

P_T = Power of signal transmitted by the system

T_I = Transmission through air/water interface

R = Reflectivity of the bottom

A = Area of receiver aperture

D = Depth of water

H = Aircraft altitude

K = Diffuse attenuation coefficient of water

The last factor shows the dominant effect of water quality, K, on the received signal. Increasing the power of the transmitted pulse, increasing the area of the receiver, and reducing aircraft altitude all help improve system performance; but if the water is murky, little penetration will be achieved.

The accuracy requirements of Figure 3 are those required for large scale hydrographic charts. Area coverage, data density, scan angle, and altitude are all operational trade-offs. For example, for small scale charts or reconnaissance, area coverage can be increased by flying higher and faster. The ability to vary the scan angle from 0 to 624 mrad (about 36^o) allows data density to be traded for area coverage. The maximum scan angle of 36^o was estimated to be of optimum efficiency; i.e., at lesser angles it is better to widen the scan

to get more coverage, and for larger scan angles it is better to fly higher. Appendix I explains how this angle was determined.

In addition to the medium range electronic positioning system specified, the HALS will also be compatible with a short-range system which can be substituted when greater horizontal positional accuracy is required. Roll, pitch, and heading angles are required to determine the position of the sounding in relation to the aircraft. The most difficult of these to maintain is the heading. The HALS will use an aircraft directional gyro which can be slaved to magnetic north in areas where compass variation is known to sufficient accuracy. In other areas, the HALS will either have to align its directional gyro to some reference marks on land or to the ship's gyrocompass. Appendix II describes how alignment to the ship's gyrocompass can be done.

The operational altitude of the system is limited by safety and depth penetration. To get maximum depth penetration, the HALS must fly as low as possible. Safety considerations normally limit this to about 150 meters. The capability to collect data at other altitudes up to 800 m is to allow a greater coverage rate when maximum data density or penetration is not required.

In order to measure accurate soundings when waves are up to 5 feet high (Beaufort scale 3), slant range altitudes from the aircraft to the surface of the water will be recorded by the system to an accuracy of $\pm$ 0.1 meter, or one part in 2,000 whichever is greater. This will be accomplished for each sounding by timing the round-trip travel of the laser pulse from the aircraft to the surface of the water. These values, at 400 Hz or more, can then be smoothed to an average sea level plane to determine a wave correction for each sounding.

There will be a radiation hazard when the system is operated. Procedures will be developed to avoid eye damage to system users or any other personnel at short range. To insure the safety of people who might look up at the HALS aircraft, the laser beam will be spread sufficiently to cause no damage at 150 meters. This will not completely absolve the pilot from avoiding personnel within the area being scanned. Someone could be looking up with binoculars.

The HALS will measure raw slant-range altitudes and depths at a rate of 400 Hz. A special mode to record the whole return signal, from the surface return to the bottom return, will also be provided, but at the slower rate of 2 or 3 Hz. These special recordings will be used to analyze the effects on the system of the different types of natural waters which will be encountered. Positional data will

HALS SPECIFICATIONS

Data Processing	Compaction
	Navigation Display
	Quick-Look
Recording	Digital
	Magnetic Tape
	1 ms Time Correlation
	Manual Inputs
	Water Depth Data
	Aircraft Altitude Data
	Horizontal Position Data
	Scanner Orientation
	Signal/Noise
	User Compatibility
Documentation	Computer Software
	Operational Manual
	Maintenance Manual
	Development Plan
	Reliability Test Plan
	Acceptance Test Plan

Figure 4

be processed to the extent necessary to provide a navigational display to the pilot, to enable him to follow the planned survey lines. The HALS will be able to confirm that valid data has been recorded immediately upon completion of a mission.

All data will be recorded digitally on magnetic tape in a format compatible with the computers on board the NAVOCEANO hydrographic survey ship. These computers may be required to do the final processing of both the positional and the depth information. It may be possible to do the final processing on the HALS computer. This is being determined as the computer programs are being developed.

The size, weight, and power requirements were determined by the limitations of the proposed aircraft, the estimated state-of-the-art of component development, and for ease-of-operation in the expected field environment. Since that time, NAVOCEANO has been reduced to one hydrographic survey ship. This reduces the amount of shipping and handling to be expected. It also appears that the HALS could have been less restricted in size, weight and power. The HH-2D currently used with the ship may be replaced by a different helicopter which will be selected with HALS in mind.

The HALS is required to be reliable in its expected environment. Its depth capability is limited by background noise, so it is not planned to use the system when the sun is over 44^{o} high. It will also not be used over ice, or when visibility is bad.

Shipping cases, spare parts, calibration equipment, maintenance equipment, training, and manuals will be procured with the system. Acceptance tests will include the airborne collection of at least 20 hours of hydrographic data and a demonstration of reliability.

HARDWARE

Figure 6 is the hardware concept. The components inside the dotted line will be in one rigid unit. The rest can be separated and connected by cables. A concept of how the system could be arranged in the cargo area of a small helicopter is shown in Figure 7.

HALS SPECIFICATIONS

Size	< $2m^3$ (70 ft^3)
Weight	< 400 kg (880 lb)
Power	< 5,000 W
Environmental	All Climate Above -2° C (28.4° F)
Visibility	> 5 km (2.7 n. mi.)
Waves	Beaufort Scale 3 (Not Breaking)
Temperature	-2° to 54° C (28.4 to 129° F)
Shock & Vibration	MIL-STD-810 C
Sun Angle	Up to 44° Altitude
Operational Life	8 Years
Reliability	100 Hours MTBF
Maintainability	4 Hours MTTR
Workmanship	MIL-STD-454E
Transport Cases	MIL-C-4150G
Training	Operator: 1 Week
	Maintenance: 2 Weeks

Figure 5

AIRCRAFT HARDWARE

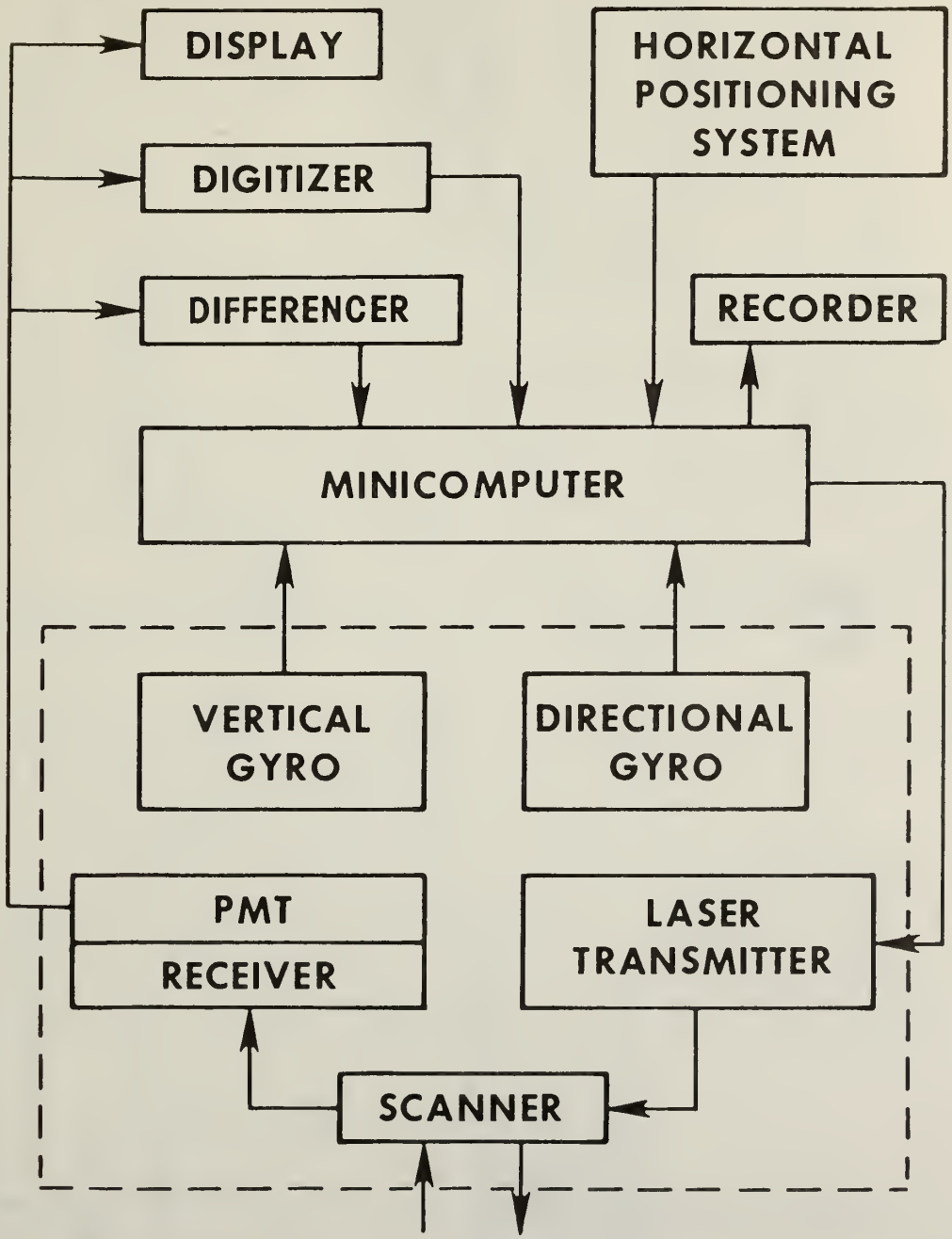


Figure 6. Hardware concept

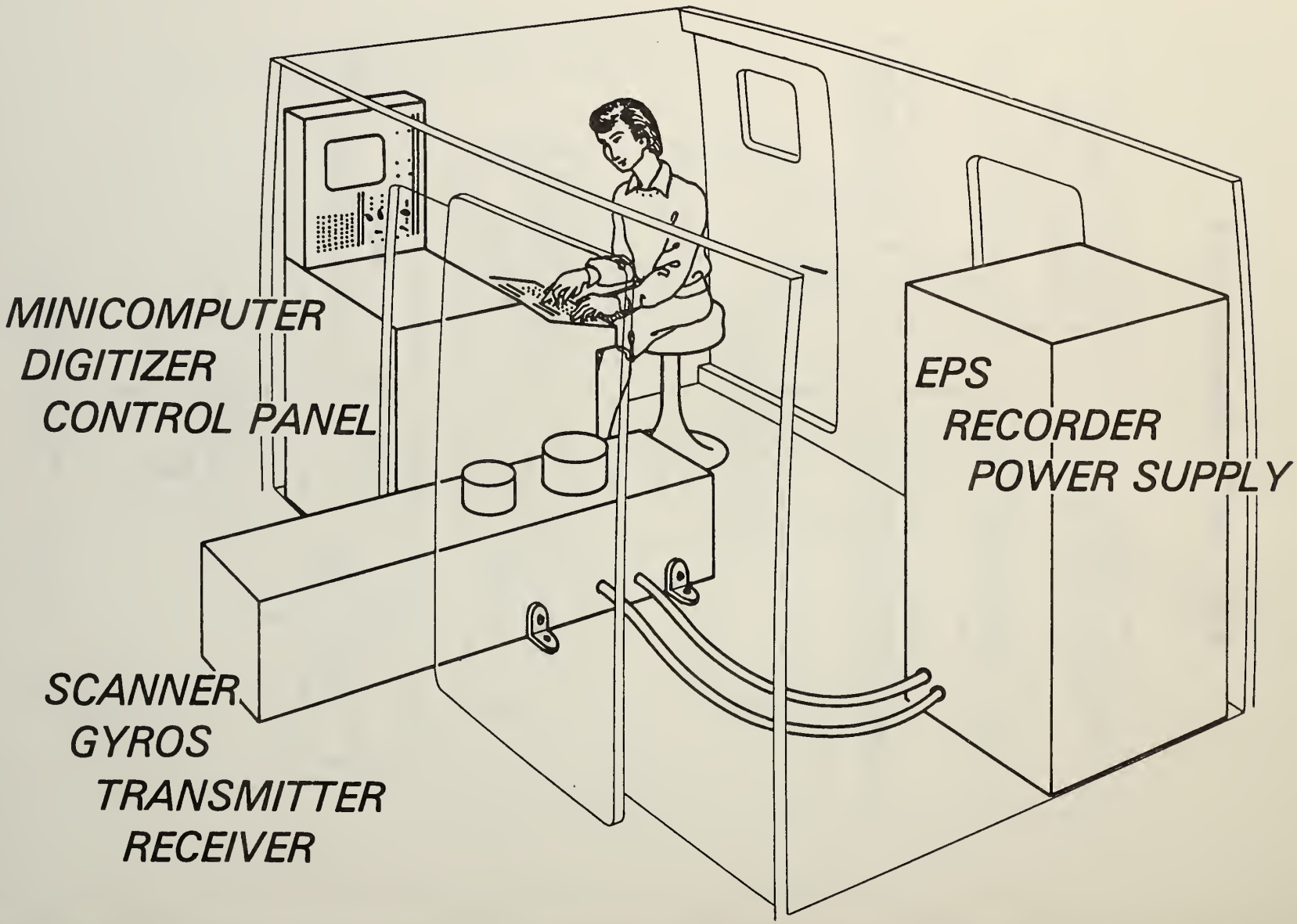


Figure 7. System arrangement in small helicopter

DATA HANDLING

Data flow is outlined in Figure 8. The pitch, roll, and heading gyro data will go the minicomputer (through an interface) get formatted, and then recorded. The depth signal from the photomultiplier (PMT) will be processed by a derivative technique in which the signal is split, one part is delayed by about one-pulse width, and the two are subtracted. This effectively eliminates the backscatter and enables the bottom return, if present, to be easily isolated electronically. A raw-depth value is then sent to the computer, time tagged and recorded. At a slower rate of 2 or 3 Hz, the signal will also be fed to a Tektronix R7912 transient digitizer. This digitized waveform is also recorded. The reason for this double handling of the depth data is that airborne laser sounders have been tested in a very limited number of environments, and the exact shape of the return signal under all conditions is not known. Further analysis of the complete waveform may be required for some types of waters and bottoms that may be encountered in the future. If only a depth value were recorded, very little analysis could be done. The derivative processor is, of course, used to achieve the desired data rate of 400 Hz. Total waveforms cannot be accurately recorded at this rate with presently available equipment.

The HALS operator will be able to call up displays of each type of depth data, the raw analog output of the PMT, and a number of other displays.

The computer selected for the HALS is a Rolm 1664. It will compact and format all the data inputs for the magnetic tape recorder, generate a trigger for the transmitter and provide a signal for the pilot's display (also available to the HALS operator). The data recorded, shown in Figure 9, will have to be further processed to reduce slant ranges in altitude and depth to the vertical, to correct for waves and tides, and to reduce the horizontal positional data. If the geodetic positions of the shore stations and the tidal correction data are manually entered into the computer, the tape will contain all the information needed to develop the hydrography (the bottom topography) of the area surveyed.

STATUS

The HALS is now being fabricated by the contractor. After acceptance tests and delivery in late 1982, NORDA plans to conduct a

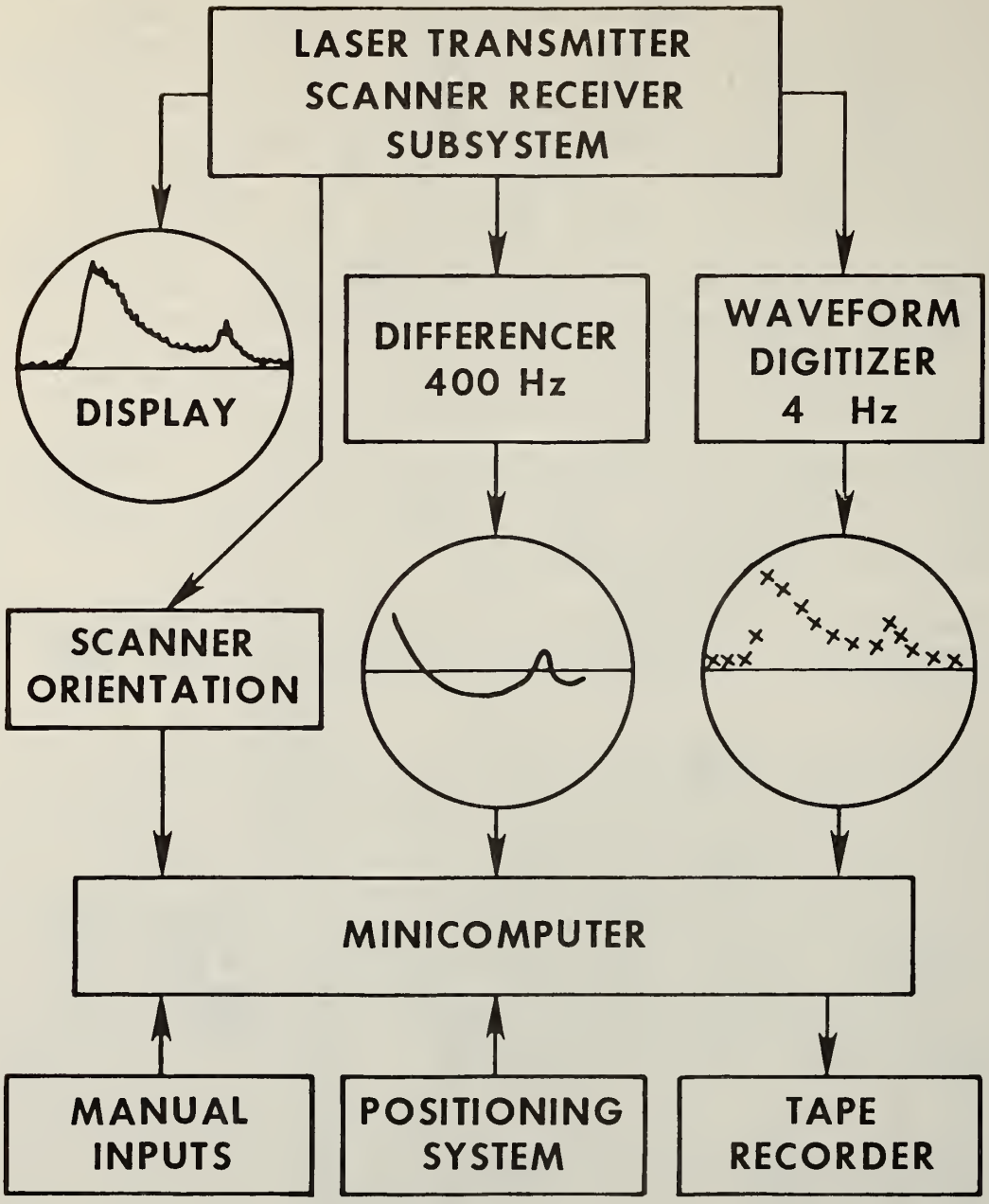


Figure 8. Data flow

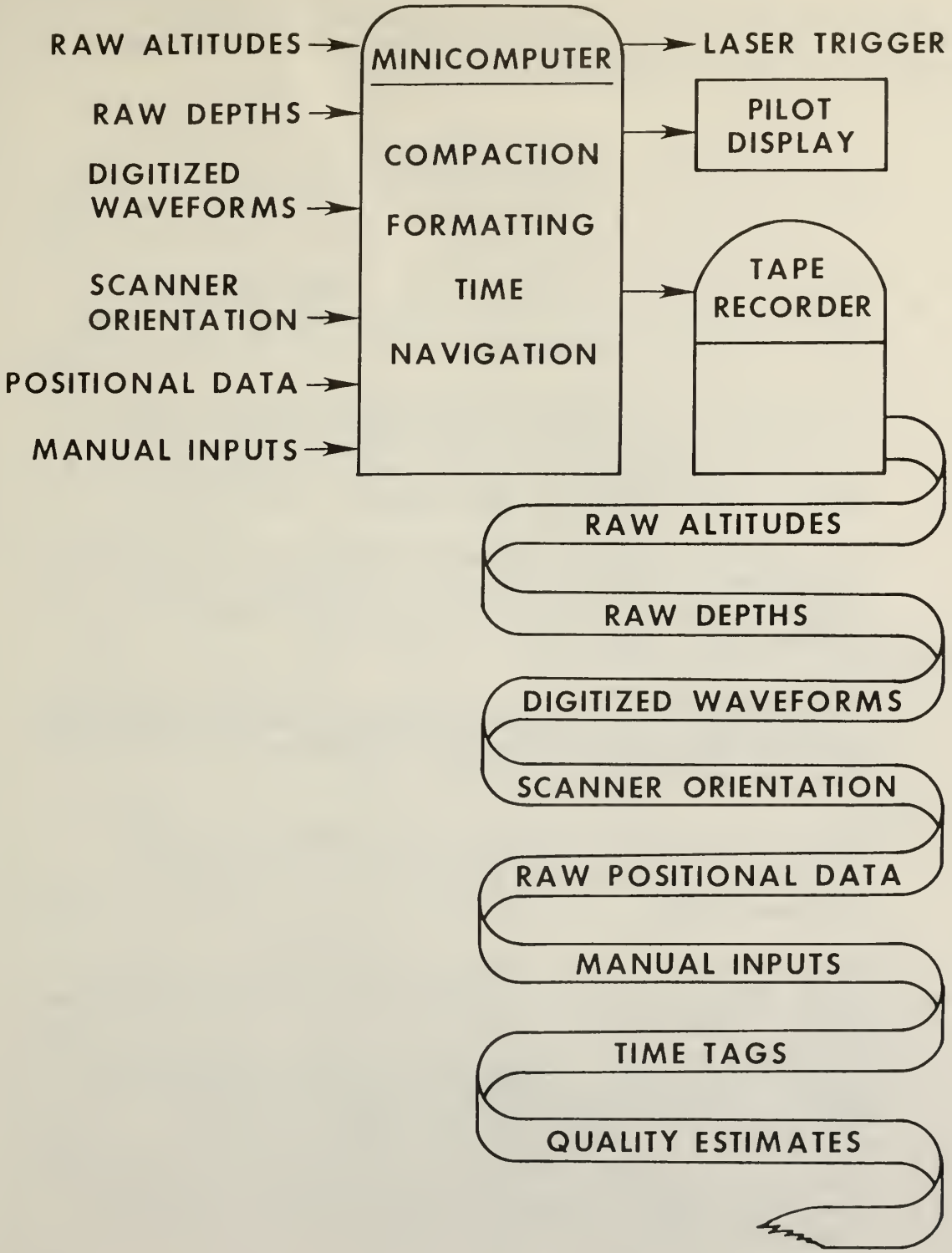


Figure 9. Data recorded

six-month field evaluation. The HALS will then be delivered to NAVOCEANO to collect hydrographic data at rates of up to 100 times faster than soundboats are doing it now.

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{3} Kim, Hongsuk H., Peter O. Cervenka, and Charles B. Lankford. "Development of an Airborne Laser Bathymeter." National Aeronautics and Space Administration, Washington, D. C., October 1975. NASA Technical Note D-8079.

{4} "Airborne Oceanographic Lidar System." Final Report, October 1975. Prepared for National Aeronautics and Space Administration, Wallops Flight Center, Wallops Island, VA 23337 by Avco Everett Research Laboratory, Inc.

{5} O'Neil, R. A. "Field Trials of a LIDAR Bathymeter in the Magdalen Islands." Data Acquisition Division, Canada Centre for Remote Sensing, Ottawa, KIA OY7, Canada, 30 September 1980.

{6} Calder, Captain M., RAN. "WRELADS - The Australian Laser Depth Sounding System." International Hydrographic Review, Monaco, LVII (1), January 1980.

{7} Purchase Description, "Hydrographic Airborne Laser Sounder (HALS). Naval Ocean Research & Development Activity, NSTL Station, MS 39529, 30 March 1979.

{8} Heaton, H. I. "Analysis of the ORIC Concept," (U), STD-R-146. The Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20810, July 1979. (SECRET)

APPENDIX I

OPTIMUM SCAN ANGLE

The NADC incorporated scanning in their system in 1971. Figure I-1 shows some of their test results at fixed off-vertical angles {3}. Figure I-2 shows how an arbitrary curve (cos 1.85 times the scan angle) can be fitted to their observed data:

$$P_\theta = P_V \cos 1.85\theta \tag{1}$$

where

$P\theta$ = Power received at scan angle θ

P_V = Power received at vertical (scan angle zero)

Figure I-3 shows the relation between altitude H, scan angle θ and swath width S:

$$\tan \theta = S/H \tag{2}$$

The amount of signal received at vertical scan is inversely proportional to the aircraft altitude squared:

$$P_V = \frac{1}{H^2} \tag{3}$$

Combining equations (1), (2), and (3):

$$S = \tan \theta \left(\frac{\cos 1.85\theta}{P\theta}\right) 1/2 \tag{4}$$

Setting $P\theta = 1$, for a given signal return, we can compute the swath width that results from any scan angle. The altitude, H, varies. Equation 4, plotted in Figure I-4, shows a maximum swath width at $\theta = 36^o$. Thus, to the accuracy of the cos 1.85 approximation to the NADC field data, $\pm 36^o$ is the optimum scan angle. At lesser angles, it is better to widen the scan to get more coverage; and at greater angles, it is better to fly higher.

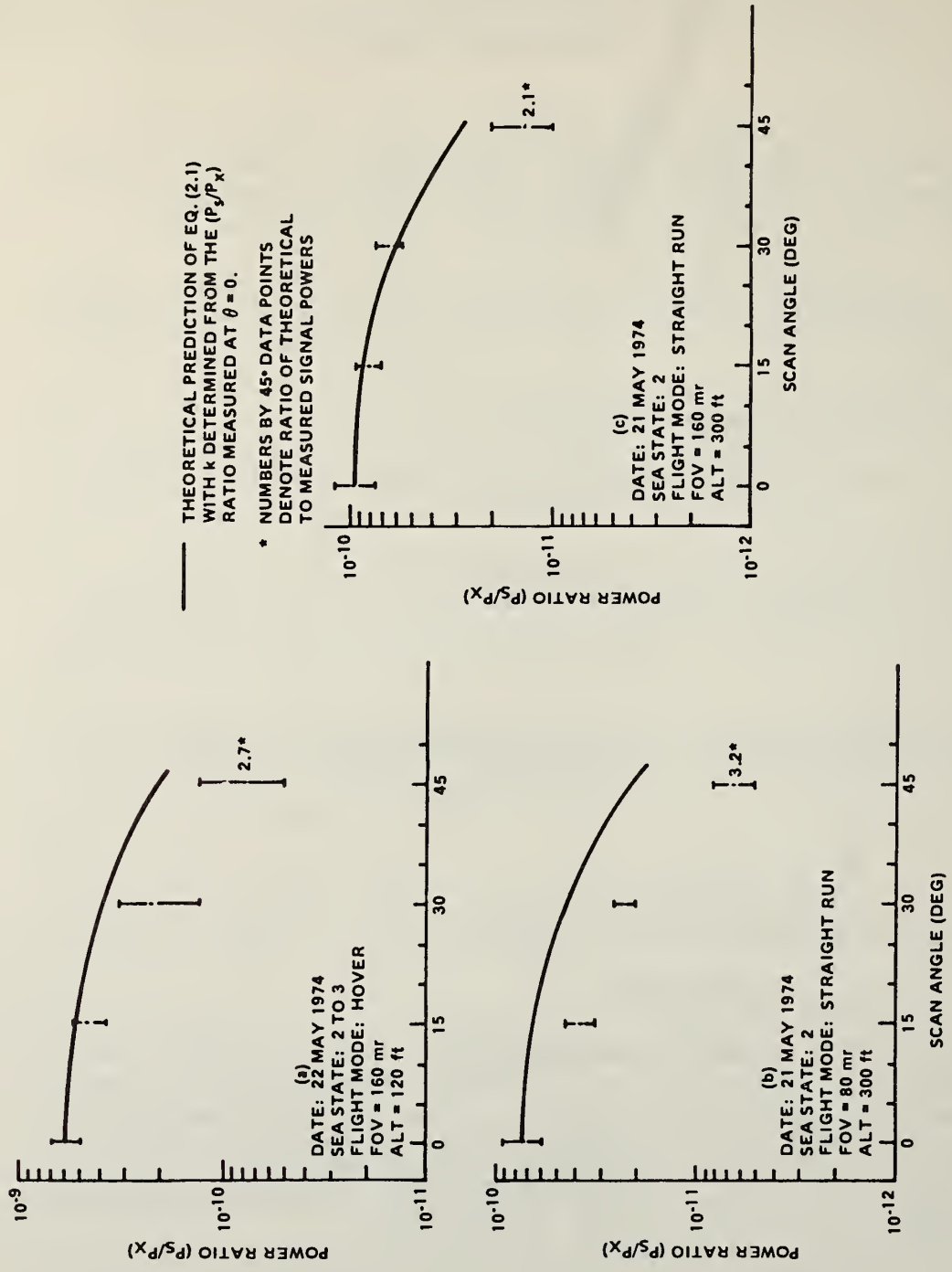

THEORETICAL PREDICTION OF EQ. (2.1) WITH k DETERMINED FROM THE (P_S/P_X) RATIO MEASURED AT $\theta = 0$.
* NUMBERS BY 45° DATA POINTS DENOTE RATIO OF THEORETICAL TO MEASURED SIGNAL POWERS
(a)
DATE: 22 MAY 1974
SEA STATE: 2 TO 3
FLIGHT MODE: HOVER
FOV = 160 mr
ALT = 120 ft
2.7*
(b)
DATE: 21 MAY 1974
SEA STATE: 2
FLIGHT MODE: STRAIGHT RUN
FOV = 80 mr
ALT = 300 ft
3.2*
(c)
DATE: 21 MAY 1974
SEA STATE: 2
FLIGHT MODE: STRAIGHT RUN
FOV = 160 mr
ALT = 300 ft
2.1*
POWER RATIO (P_S/P_X)
SCAN ANGLE (DEG)

Figure I-1. Test results at fixed off-vertical angles

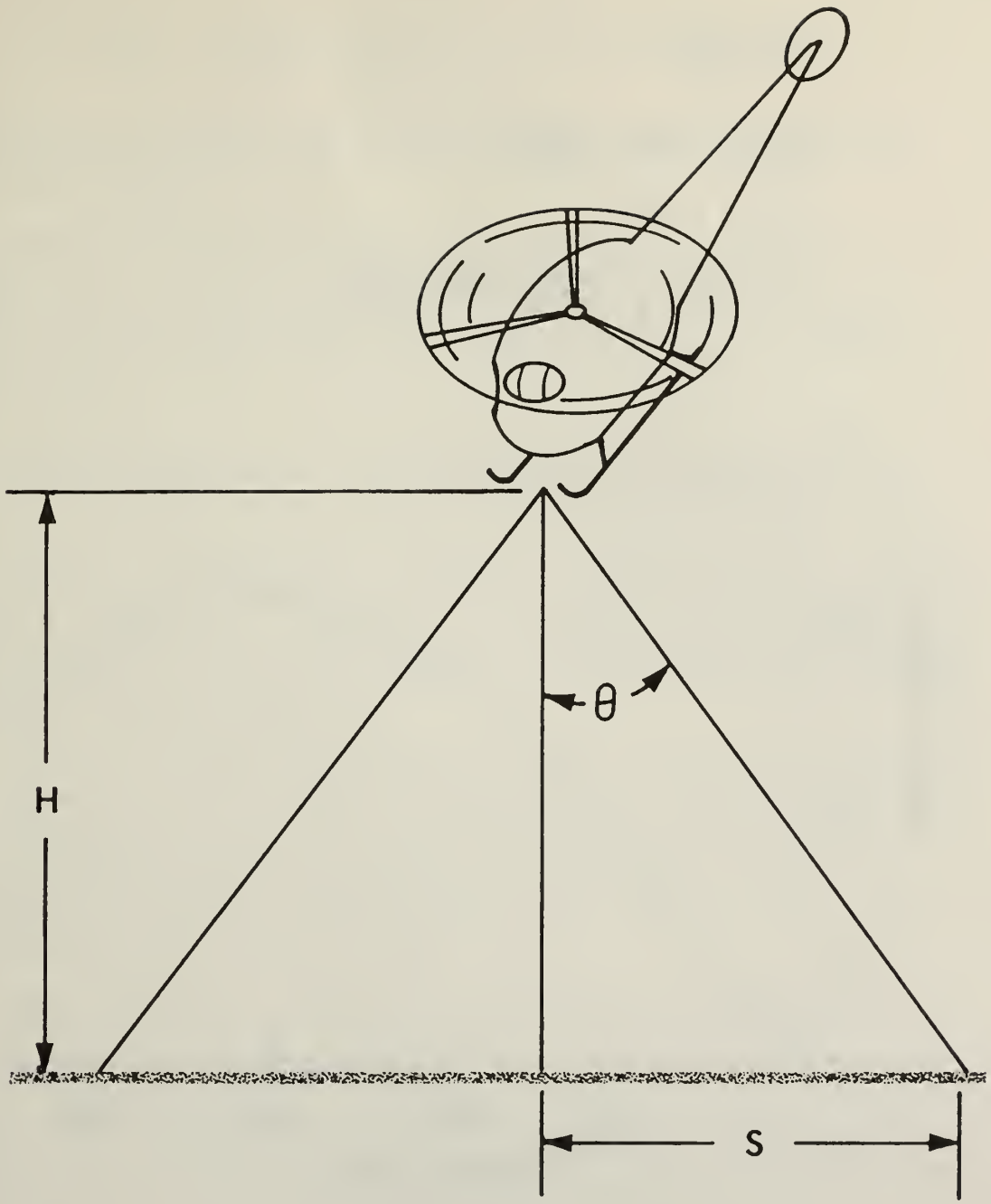


Figure I-3. Relation between altitude H, scan angle θ, and swath width S

$$P_V = \frac{1}{H^2}$$

$$P_\theta = P_V \cos 1.85\theta$$

$$\tan\theta = S/H$$

$$S = \tan\theta \left(\frac{\cos 1.85\theta}{P_\theta}\right)^{1/2}$$

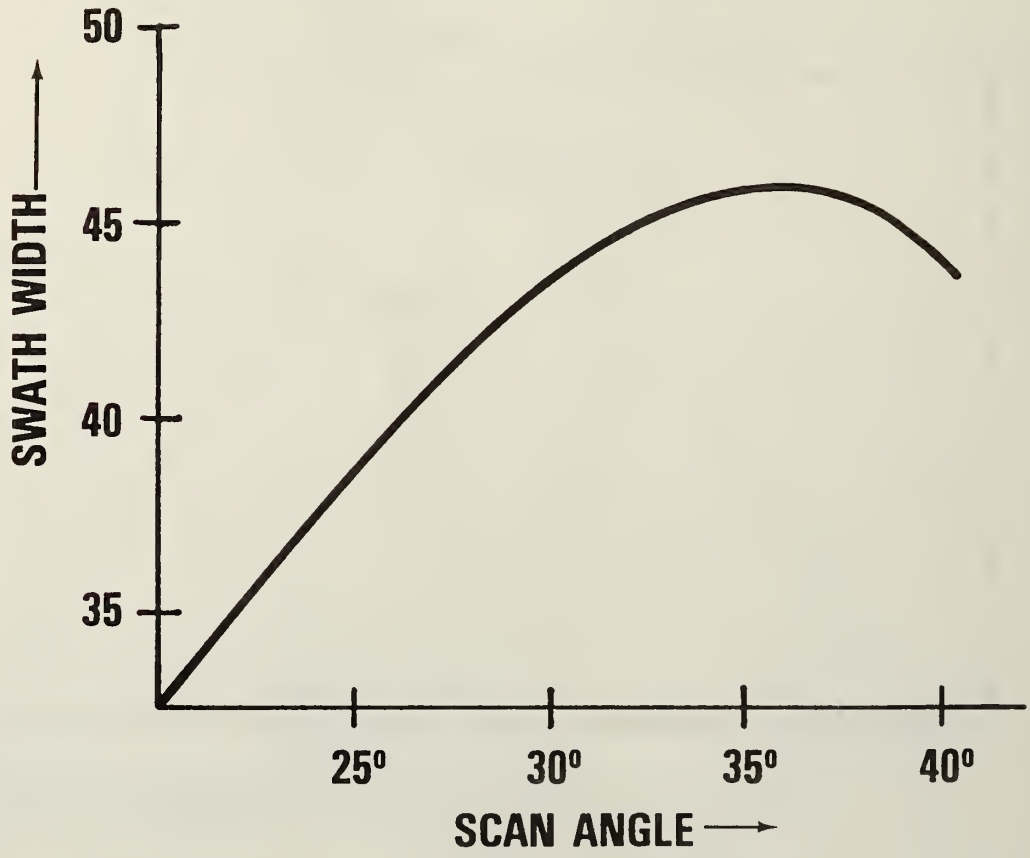


Figure I-4. Maximum swath width at $\theta = 36^0$

APPENDIX II

SHIPBOARD ALIGNMENT PROCEDURE FOR HALS DIRECTIONAL GYRO

1. Mark a straight line (line A-B in Figure II-1) on the ship's deck in the area where the HALS helicopter is most apt to be prior to a HALS mission.

2. Measure the bearing of this line in relation to the ship's lubber line. This can be done most accurately when in port, using ground survey equipment to measure the azimuth of line A-B and using the ship's gyrocompass to measure the azimuth of the lubber line. The gyrocompass will be at its maximum accuracy when the ship is tied up.

3. Select two points on the HALS helicopter, fore and aft, for attachment of plumb bobs. The points should be permanent, as far apart as possible, and as low as possible to reduce plumbing errors.

4. Determine the horizontal alignment of the HALS scanner in relation to the line determined by the 2 plumb bob points. This is shown as angle Z in Figure II-1, and is the angle between the "zero" on the azimuth encoder of the scanner mirror to the calibration line determined by the plumb bob points. Subsequent data analysis will provide checks on this measurement.

5. To align the HALS directional gyro before a mission, align the helicopter with the line on the deck using the 2 plumb bobs. Take the heading (angle H in Figure II-1) from the ship's gyrocompass, add the bearing (angle C in Figure II-1) of the line on the deck, subtract the scanner alignment (angle Z on Figure II-1) and set the resultant azimuth into the directional gyro. This value should be checked immediately before takeoff.

6. After the mission, leave the directional gyro running and realign the helicopter to the deck reference line. Read the ship's gyrocompass and the HALS directional gyro. Compare their difference with the known calibration difference and record the total directional gyro drift. The times of the initial setting or the pre-mission check and the post-mission comparison must also be recorded so the drift, if significant, can be applied to the headings recorded during the mission.

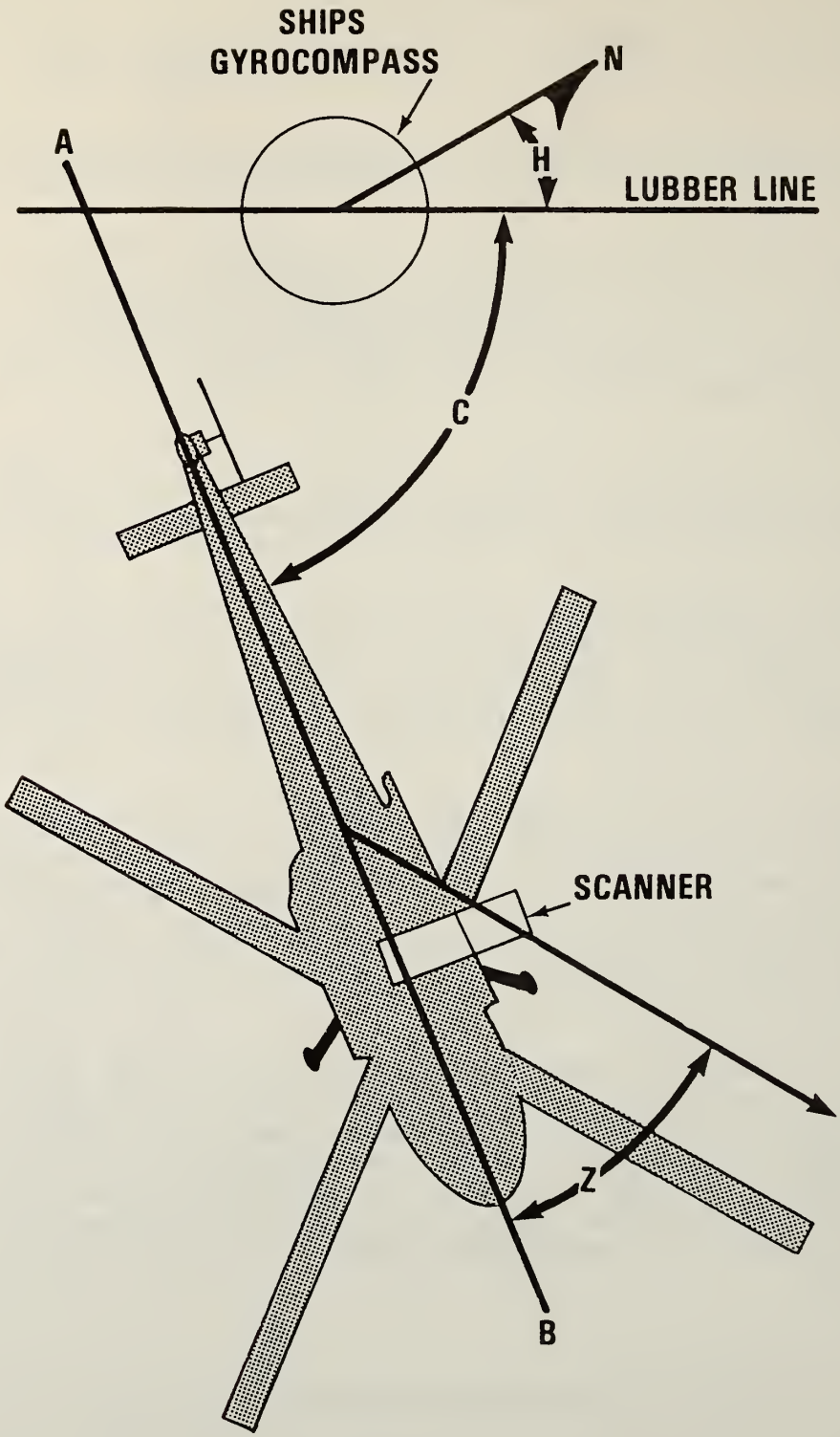


Figure II-1. Shipboard alignment procedure

MR. BRIGHT: Are there any questions on this?

TOM STEPKA, NOS: I was wondering if you could say a few words about the processing, post survey processing of the vast amount of data that it seems like you are going to be collecting.

What sort of scheme do you have for processing? Can you do it on the ship, for example?

MR. BRIGHT: Hopefully the HALS computer itself will be able to do all the processing. However, there is a big problem being worked on, optimal data reduction program, which uses like a common filter, only in a smoothing mode, to get the minimum variance based on the fact that you have a certain amount of smoothness of the bottom, and you can relate one sounding to another sounding, and increase the accuracy considerably by doing that, and also the program for the wave corrections requires quite a bit of space. So, if it can't be done on the computer, on the HALS, it will be done on the shipboard computer. There are no plans to do any further data reduction ashore or back in the plant or anything like that.

LCDR M.M. ETHRIDGE, Coastal Mapping Division: I was wondering what accuracies you were projecting for the depth soundings.

MR. BRIGHT: We are required to get to within 28 centimeters -- that is the specification as shown -- out to 20 meters.

So, that is the accuracy that we are planning on getting. It is very difficult to obtain, and it has caused considerable trouble, but that is the equipment accuracy that is projected right now.

Now, that includes the smoothing process afterwards. Perhaps in extremely rough terrain, there might be difficulty in achieving a one-foot accuracy. It hasn't been determined yet how bad it will get in rough terrain.

Thank you.

LCDR YEAGER: Thank you very much, Mr. Bright.

ARTEMIS FIELD TEST

Cdr. Ludvik Pfeifer
Marine Data Systems Project
Office of Marine Surveys and Maps
National Ocean Survey, NOAA
Rockville, MD 20852

ABSTRACT. ARTEMIS is a single-user range-azimuth microwave positioning system manufactured in the Netherlands. The system is especially well suited for close inshore hydrography at large surveying scales, in which capacity it would fill an existing void as an electronic positioning system. This paper describes the execution of a field test of the ARTEMIS equipment.

INTRODUCTION

A field test of the ARTEMIS positioning system was carried out on May 17, 1980, by the personnel of the NOAA Ship MT. MITCHELL (S-222) in Galveston, Texas. The ARTEMIS equipment was made available for this purpose by the Houston office of MARINAV Inc., who also provided technical personnel to assist with the installation and operation of the ARTEMIS system. The coordination with MARINAV was accomplished through Mr. J. Hume, General Manager of the Houston office.

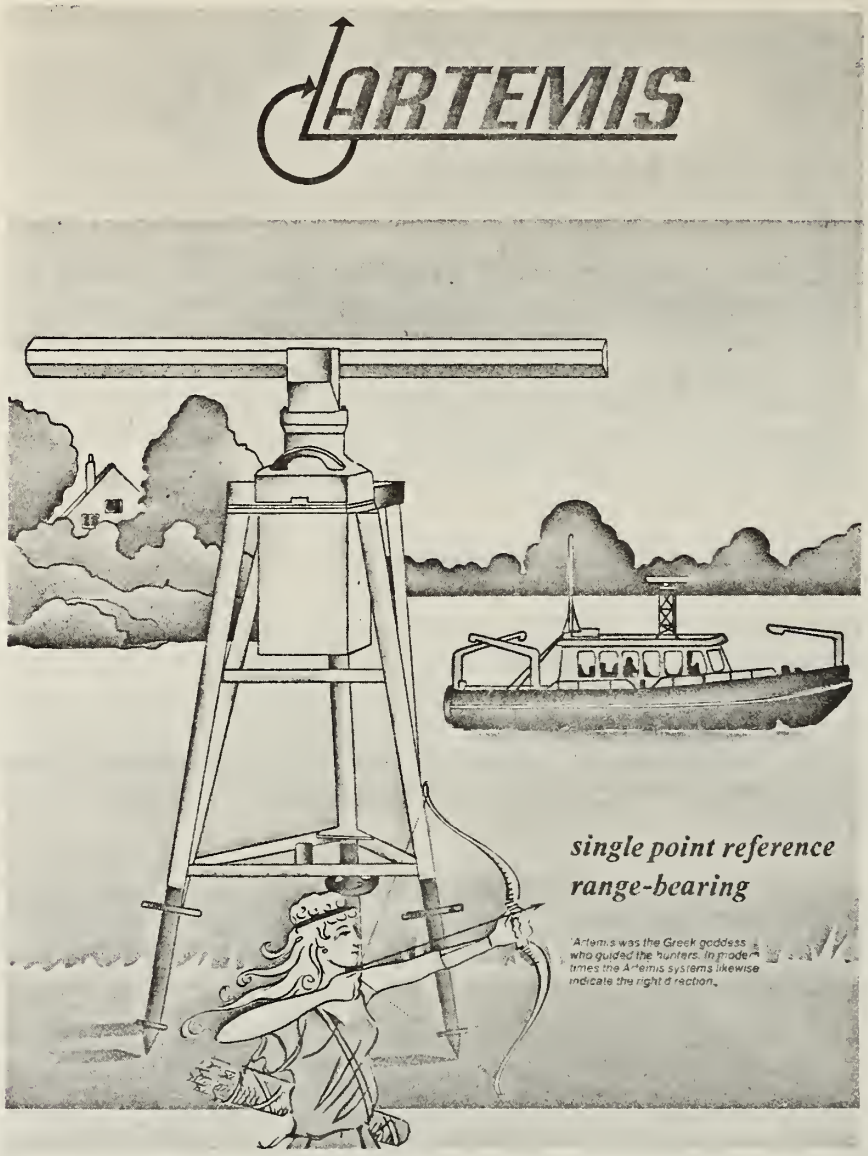
The test was planned and executed under the direction of the ship's Field Operations Officer, Lt. Cdr. Ronald W. Jones. The data processing and interpretation of the results were accomplished by Cdr. Ludvik Pfeifer, the ship's Executive Officer.

THE ARTEMIS SYSTEM

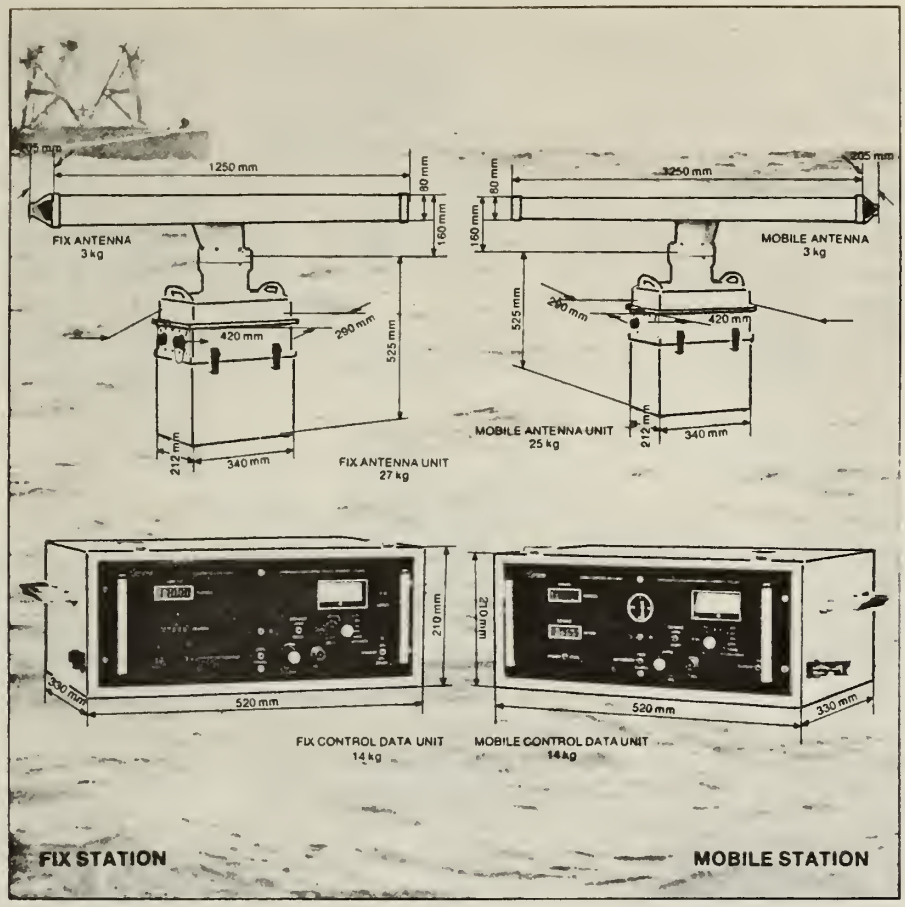
ARTEMIS is a microwave line-of-sight, single-user range-azimuth positioning system manufactured by the Christiaan Huygenslaboratorium, Noordwijk, The Netherlands. The equipment which comprises a complete system consists of a shore ("FIX") station antenna unit and control unit, and of a mobile station antenna unit and control unit -- see illustration on the next page. The prominent feature of the ARTEMIS equipment is the rotating horizontal waveguide antenna, resembling a shipboard radar antenna, which is mounted atop the shore and mobile antenna units. In operation, the shore and mobile antennas lock onto each other and swing in azimuth as the mobile station maneuvers.

At the outset of operations, the shore station antenna is initialized by sighting to an azimuth reference object through a removable attachment telescope and by setting the corresponding azimuth into the shore station control unit by means of a thumbwheel input device. Thereafter, the range and azimuth

from shore station to the mobile station are instantaneously available for display at both ends of the microwave link and for interface with data processing equipment aboard the vessel.


ARTEMIS
single point reference
range-bearing
Artemis was the Greek goddess who guided the hunters. In modern times the Artemis systems likewise indicate the right direction.

The advertised maximum range in the system's "LONG" mode is 30Km (1.4Km in the "SHORT" mode which features enhanced range resolution and accuracy); however, line-of-sight geometry of the radar horizon under typical conditions of shore and mobile station antenna height will normally limit the working range to 12 or 15 kilometers. Both the shore and mobile stations operate from a 24Volt DC power source (e.g. two automative batteries) and draw approximatel 3A of current. The present (1980) cost of one system is in the neighborhood of $150,000.



The obvious operational advantages of the ARTEMIS system are:

1. Portability, ease of operation, and simplicity of data processing.

2. Freedom from geometric limitations on the accuracy of the position fix (the "intersection angle" is always 90^{o}).

3. Only one shore station (and hence only one unobstructed line of sight) is required.

4. The system uses highly directional antennas which maintain a lock on each other, thereby maximizing signal gain, minimizing interference by signals reflected from vertical features, and generally enhancing the system's operating reliability.

5. Ability to operate in close proximity to the shore station with maximum accuracy of the system.

6. Radial (range-measurement) error is independent of distance from the shore station; increased range-measurement resolution and accuracy are available in the "SHORT" mode.

7. Voice communication capability over the microwave link.

Frequency	: 9.2 - 9.3 GHz		
Radiated microwave power	: 150 mW - distance long 1.5 mW - distance short		
Distance Measurement			
Distance short/long switch set to	:	Short	Long
Range	:	10 - 1400 m	200 - 30000 m
Overall accuracy (2 Sigma)	:	0.5 m	1.5 m
Display	:	5 digits LCD type	
Dynamic mode	:		
Resolution	:	1 m	1 m
Renewal rate	:	60 msec	0.25 sec
Static mode	:		
Resolution	:	0.1 m	0.1 m
Renewal rate	:	0.6 sec	2.5 sec
Azimuth measurement			
Range	: 0 - 360 degrees ; 0 - 400 grads internal switchable		
Overall accuracy (2 Sigma)	: 0.03 degree ; 0.04 grad		
Display	: 5 digits LCD type		
Resolution	: 0.01 degree; 0.01 grad		
Output format			
Distance and Azimuth	: BCD (+ 8421), TTL, parallel out, with data ready pulse.		
Antenna			
Horizontal beamwidth	: approx. 2°		
Vertical beamwidth	: approx. 22°		
Side lobes	: <-32dB		
Gain	: approx. 28dB		
Tracking characteristics			
Max. tracking speed (FIX)	: 15°/sec		
Max. tracking speed (MOBILE)	: 30°/sec		
Max. tracking speed with angle error within limits of specification	: 3°/sec		
Power consumption	: + 24V $^{+5V}_{-3V}$; approx. 3A;	overvoltage protection. undervoltage indication.	
Weights and Dimensions	: see page 3.		
Housing			
Antenna and Antenna Unit	: suitable for exposed conditions		
Control Data Unit	: splash proof		
Temperature range	: -20° — + 55°C		
Storage	: -30° — + 70°C		

The ARTEMIS system has been designed and is produced by CHRISTIAAN HUYGENS-LABORATORIUM B.V. Noordwijk, The Netherlands.
Data subject to change without notice.

Some of the operational drawbacks of the ARTEMIS system are:

1. As is the case with all microwave line-of-sight systems, the operating range is limited by the radar horizon, which normally results in half or less of the system's maximum range of 30Km to be attainable. Also, the system's operation is subject to the effects of destructive interference of multipath propagation due to reflection of signals from the water surface.

2. The shore station antenna unit must be mounted on a four-foot stand (to allow height-of-eye access for orientation on an azimuth reference object). The stand must be sufficiently rigid to resist torsion and must be firmly anchored in the ground (or affixed to the supporting structure) to avoid

accidental disturbing which would introduce a shift into the azimuth data. These requirements preclude the option of increasing antenna height by mounting the shore station unit atop a mast.

3. Although the system is engineered so that the shore station can operate unattended, in most locations personnel will have to stand by to guard against willful or accidental disturbance and to verify orientation of the shore station antenna at intervals.

4. Tangential error, being the product of the tangent of the azimuth-measurement error and range, increases linearly with distance from the shore station.

RADAR HORIZON

Since the radar horizon sets an absolute limit on the attainable operating range of a microwave line-of-sight positioning system, a table of maximum ranges computed for representative values of shore station and mobile station antenna heights is given below. The limiting ranges were computed by the formula given in Ref. 1, p. 4-25.

$$D = 4.04(\sqrt{h} + \sqrt{k})$$

Where: D = maximum over-the-radar-horizon range, in kilometers
h = shore station antenna height, in meters
k = mobile station antenna height, in meters

TABLE I
MAXIMUM OVER-THE-RADAR-HORIZON RANGE
IN KILOMETERS
AS A FUNCTION OF SHORE AND MOBILE ANTENNA HEIGHTS

SHORE ANTENNA HEIGHT	MOBILE ANTENNA HEIGHT			
	3m	5m	10m	20m
2m	12.7	14.7	18.5	23.8
5m	16.0	18.1	21.8	27.1
10m	19.8	21.8	25.6	30.8
20m	25.1	27.1	36.1	
30m	29.1	31.2		
40m	32.5			

LAYOUT AND EXECUTION OF THE TEST

For the purpose at hand, the ARTEMIS mobile station was installed in one of the ship's "Jensen" survey launches which, in addition, was equipped with the master station of a standard NOS-owned Del-Norte TRISPONDER system. The method employed to carry out the test was to obtain a series of simultaneous intersection cuts to the ARTEMIS mobile antenna unit from two theodolites and ranges from two TRISPONDER remote stations, in addition to the corresponding ARTEMIS range-azimuth data, under various conditions of speed and heading of the survey launch.

Given that the azimuth-measurement error of the ARTEMIS system translates into a tangential error which, for any given position fix, is directly proportional to distance from the shore station, the primary objective of the test was to evaluate the performance of the ARTEMIS system at the longest possible range, where its operation would be marginal and the effect of its errors maximized. Conversely, the layout of the test should endeavor to minimize the effect of errors of the controlling systems, i.e., of the theodolite intersection cuts and TRISPONDER ranges.

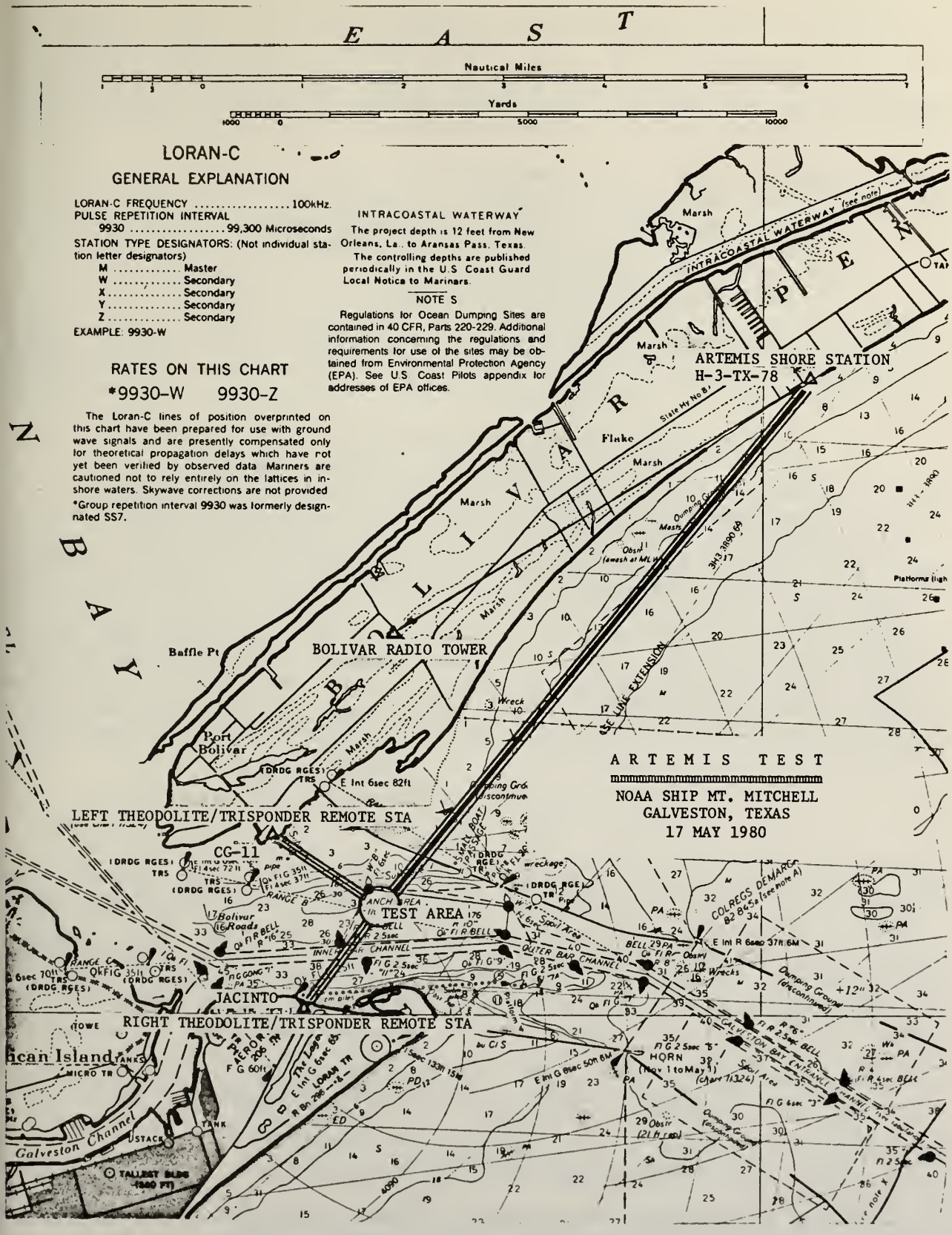
The test layout selected (see chartlet on the following page) fulfilled the objective of forcing the ARTEMIS system to operate under marginal conditions. With the shore station antenna height of 2 meters and mobile station antenna height of 3 meters, the maximum attainable range predicted (see RADAR HORIZON) was 12.7Km. The actual ARTEMIS range data acquired in the course of the test varied from 11.5 to 12.5Km. The layout also fulfilled the objective of minimizing the effect of error in the controlling systems. The distances from the left and right theodolite/TRISPONDER remote stations to the survey launch ranged from 2.1Km to 3.4Km, and the intersection angle at the survey launch was always near 90 degrees.

The relevant horizontal control data are summarized in the table below.

TABLE II
SUMMARY OF HORIZONTAL CONTROL DATA

STATION	LATITUDE	LONGITUDE
CG-11 -- Left Theodolite Station	29 21 47.066	94 45 29.697
JACINTO -- Right Theodolite Station	29 20 03.945	94 45 09.213
Left TRISPONDER Remote (CG-11 ECC)	29 21 47.027	94 45 29.793
Right TRISPONDER Remote (JACINTO ECC)	29 20 03.966	94 45 09.242
H-3-TX-78 -- ARTEMIS Shore Station	29 26 19.696	94 39 26.559
BOLIVAR RADIO TOWER -- Azim Ref Pt	29 23 48.360	94 44 13.479

The test proper was executed under excellent weather conditions in the span of two hours, 1000 to 1200, on May 17, 1980.


E A S T
Nautical Miles
Yards
LORAN-C
GENERAL EXPLANATION
LORAN-C FREQUENCY ..... 100kHz.
PULSE REPETITION INTERVAL
9930 ..... 99,300 Microseconds
STATION TYPE DESIGNATORS: (Not individual station letter designators)
M ..... Master
W ..... Secondary
X ..... Secondary
Y ..... Secondary
Z ..... Secondary
EXAMPLE: 9930-W
RATES ON THIS CHART
*9930-W 9930-Z
The Loran-C lines of position overprinted on this chart have been prepared for use with ground wave signals and are presently compensated only for theoretical propagation delays which have not yet been verified by observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided
*Group repetition interval 9930 was formerly designnated SS7.
INTRACOASTAL WATERWAY
The project depth is 12 feet from New Orleans, La., to Aransas Pass, Texas.
The controlling depths are published periodically in the U.S. Coast Guard Local Notice to Mariners.
NOTE S
Regulations for Ocean Dumping Sites are contained in 40 CFR, Parts 220-229. Additional information concerning the regulations and requirements for use of the sites may be obtained from Environmental Protection Agency (EPA). See U.S. Coast Pilots appendix for addresses of EPA offices.
ARTEMIS SHORE STATION
H-3-TX-78
BOLIVAR RADIO TOWER
LEFT THEODOLITE/TRISPONDER REMOTE STA
RIGHT THEODOLITE/TRISPONDER REMOTE STA
CG-11
TEST AREA
JACINTO
ARTEMIS TEST
NOAA SHIP MT. MITCHELL
GALVESTON, TEXAS
17 MAY 1980
INTRACOASTAL WATERWAY (see note)
BOLIVAR PENINSULA
BAY
Baffle Pt
Port Bolivar
Galveston Channel
Marsh
Flake
State Hy No 87
COLREGS DEMARCATION LINE (See note A)
Dumping Ground (for continued)
Platforms (high)
TALLEST BLDG (1000 FT)

THE TEST DATA

The data acquired in the course of this test consisted of "positions," each position being a sextuplet of simultaneously observed measurements, as follows:

1. Azimuth from the left theodolite station
2. Azimuth from the right theodolite station
3. Range from the left Del-Norte TRISPONDER remote
4. Range from the right Del-Norte TRISPONDER remote
5. Range from the ARTEMIS shore station
6. Azimuth from the ARTEMIS shore station

The total of 71 positions were attempted, eight of which had incomplete theodolite azimuth data and hence were considered as missed, leaving 63 position with complete data. The positions were taken in seven groups, as follows:

1. Pos 1-10 -- Initial calibration at anchor
2. Pos 11-21 -- Low speed (5KTS) run on courses 280 and 100
3. Pos 22-31 -- Medium speed (7KTS) run on courses 280 and 100
4. Pos 32-41 -- High speed (11KTS) run on courses 280 and 100
5. Pos 42-54 -- Medium speed (7KTS) run on courses 220 and 040
6. Pos 55-64 -- Medium speed (7KTS) zig-zag run on courses 310 and 240
7. Pos 65-71 -- Terminal calibration adrift

It should be noted, for later reference, that groups 2, 3, and 4 were low, medium, and high speed runs toward and away from the left theodolite station and nearly broadside to the ARTEMIS shore station. Group 5 was a medium spee run away from and toward the ARTEMIS shore station, approximately toward and away from the right theodolite station, and broadside to the left theodolite station.

DATA PROCESSING

The computations required to accomplish the reduction and analysis of th acquired test data were performed on a Hewlett-Packard HP-9815A desktop computer. A rigorous treatment of the data was possible because of a series of programs written for this computer by the author, the development of which ha only recently been finalized (HP-9815A GEODETIC PACKAGE Version 800610). The following Geodetic Package programs were used in the course of processing the data at hand:

GP-01 -- 150Km Geodetic Direct, Inverse, and Traverse
GP-02 -- Position by Open Traverse with Error Propagation
GP-05 -- Position by Trilateration - 2 or More Ranges
GP-06 -- Position by Intersection - 2 or More Azimuths
GP-08 -- Position by Adjustment of a Single Point

As the initial step, the position (latitude and longitude) of the ARTEMI mobile antenna unit was computed for each of the 63 complete data points usin the theodolite intersection data (left and right azimuths). The inverse dis-

tance and forward/back azimuths were then computed between this position of the ARTEMIS mobile antenna unit and the left TRISPONDER remote, the right TRISPONDER remote, and the ARTEMIS shore station for all 63 data points. The left and right TRISPONDER ranges were then corrected for the offset of the master TRISPONDER antenna from the ARTEMIS antenna on the survey launch, based on the heading of the survey launch and computed back azimuth data.

Next, the constant measurement error affecting the left and right TRISPONDER ranges and the ARTEMIS range and azimuth were determined (see CALIBRATION OF THE TRISPONDER AND ARTEMIS SYSTEMS) and appropriate corrections were applied to the respective indicated measurements. Finally, for each data point, all six observations (theodolite azimuths, TRISPONDER ranges, and ARTEMIS range and azimuth) were combined in a least-squares solution which produced an "adjusted" position of the respective data point, and a statistical analysis was performed on the resulting sets of residuals (see ANALYSIS OF THE TEST DATA).

CALIBRATION OF THE TRISPONDER AND ARTEMIS SYSTEMS

The comparison of the results of the initial and terminal calibrations of the ARTEMIS range and azimuth confirmed the expected stability of this system, as the initial and terminal range calibration values differed only by 0.5m, while the corresponding azimuth calibration values agreed exactly. The pooled calibration values, based on the aggregate of the 10 positions in the initial calibration data group and the 5 positions in the terminal calibration data group, were as follows:

TABLE III
ARTEMIS CALIBRATION CORRECTIONS

ARTEMIS RANGE	-3.4 meters
ARTEMIS AZIMUTH	-0°02 (-72")

The comparison of the results of the initial and terminal calibrations of the left and right TRISPONDER ranges, on the other hand, gave further evidence of the well-known inherent instability of the Del-Norte TRISPONDER system. In the span of two hours which separated the initial and terminal calibrations, the constant measurement error in the left and right TRISPONDER ranges changed +3.3m and -2.3m, respectively. As the expected accuracy of the TRISPONDER ranges did not warrant prorating these differences, the calibration values finally adopted were based on the aggregate of the 10 positions in the initial calibration data group, the 5 positions in the terminal calibration data group, and the 10 positions in the second data group (low speed run), for which the theodolite intersections were deemed still sufficiently accurate:

TABLE IV
TRISPONDER CALIBRATION CORRECTIONS

LEFT TRISPONDER RANGE (P2)	+6.5 meters
RIGHT TRISPONDER RANGE (P1)	+5.0 meters

ANALYSIS OF THE TEST DATA

Since the end results of this test were to be obtained by statistical analysis of the residuals produced by a least-squares adjustment of the individual positions, allowing for the combination of all six measurements at each data point, a careful thought had to be given to the weights assigned to the respective measurements, which is to say that the standard errors (sigma values) to be associated with the measurements in question had to be carefully evaluated.

For the theodolite azimuth observations, the standard errors were selected with due regard to the fact that the tracking error increases rapidly with the speed of the target's motion across the field of view. Accordingly, after taking into consideration the speed and heading of the survey launch in each data group, the following sigmas were assigned to the left and right theodolite azimuth observations:

TABLE V
STANDARD ERRORS ASSIGNED TO THEODOLITE AZIMUTH OBSERVATIONS

TEST DATA GROUP	POSITIONS	AZIM SIGMAS IN SECONDS		LATERAL DIST AT 3 KM	
		LEFT AZIM	RIGHT AZIM	LEFT AZIM	RIGHT AZIM
1	1-10	10"	10"	0.1m	0.1m
2	11-21	30"	90"	0.4m	1.3m
3	22-31	60"	180"	0.9m	2.6m
4	32-41	120"	360"	1.7m	5.2m
5	42-54	180"	60"	2.6m	0.9m
6	55-64	120"	120"	1.7m	1.7m
7	65-71	20"	20"	0.3m	0.3m

Unlike the standard errors of the theodolite observations, those of TRISPONDER ranges, ARTEMIS ranges, and ARTEMIS azimuths are expected to be constant, i.e., independent of the position and motion of the survey launch.

A first estimate of the standard error of a TRISPONDER range measurement was obtained as the RMS value of the set of residuals (i.e., difference between the computed inverse distances and the corresponding observed left and right TRISPONDER ranges). Examination of these residuals revealed the presence of four large outliers, all spurious left TRISPONDER (Pattern P2) range indications, probably caused by interference due to signal reflection from nearby ships and barges. Susceptibility to such spurious "jumps" is a well-known weakness of the Del-Norte TRISPONDER system. After rejecting these four data points (positions 25, 26, 33, and 55) and omitting the 15 positions of the initial and terminal calibration data groups, the remaining 88 residuals (44 left and 44 right range residuals) yielded the RMS estimate of 5.8 meters.

The same procedure was followed to obtain a first estimate of the standard errors of the ARTEMIS range and azimuth. In this instance, 44 range residuals yielded the RMS estimate of 2.8m for an ARTEMIS range, and 44 azimuth

TABLE VI
SUMMARY OF RESIDUALS

	FIRST ADJUSTMENT						SECOND ADJUSTMENT					
POS	LAZ (sec)	RAZ (sec)	LDN (m)	RDN (m)	RNG (m)	AZ (deg)	LAZ (sec)	RAZ (sec)	LDN (m)	RDN (m)	RNG (m)	AZ (deg)
12	-4	+16	+4.1	-3.4	+1.9	+0.07	-10	+16	+4.1	-3.3	+1.8	+0.02
13	-1	+4	+3.0	-2.9	+0.7	+0.04	-6	-12	+2.8	-2.9	+0.7	+0.01
14	-5	+36	-2.9	-2.1	+2.7	+0.03	-13	+78	-1.3	-1.9	+2.3	-0.02
15	-2	+19	+0.6	-2.9	+1.9	+0.04	-11	+32	+0.9	-2.7	+1.8	-0.01
16	-4	+24	+0.6	-2.1	+2.4	+0.06	-11	+46	+1.0	-2.0	+2.2	+0.01
17	0	-9	+1.8	+0.7	-0.2	0.00	-1	-45	+1.4	+0.5	0.0	-0.04
18	+1	+4	-1.4	+0.5	0.0	0.00	0	-9	-1.6	+0.4	+0.1	-0.05
19	+3	-15	+1.4	+0.4	-1.7	+0.01	+6	-59	+0.5	+0.1	-1.3	-0.03
20	-2	+25	-3.2	-1.1	+0.6	+0.04	-5	+49	-2.8	-1.0	+0.4	-0.01
21	+3	-10	-1.1	-0.1	-2.8	+0.03	+13	-42	-1.7	+0.4	-2.4	-0.01
22	-9	+100	-1.2	-2.9	+0.1	+0.03	-17	+125	-1.7	-2.5	-0.2	+0.02
23	-12	+131	-3.8	+1.6	+1.4	+0.05	-21	+183	-2.8	+1.2	+1.0	-0.01
24	-2	+112	+3.4	-0.6	-0.2	+0.07	+2	+162	-2.6	-0.2	-0.5	+0.01
27	+12	+42	-3.4	+2.2	-1.5	+0.06	+37	+55	-3.3	+2.9	-1.2	+0.01
28	+13	+40	-2.2	+5.1	-0.8	+0.08	+35	+47	-2.3	+4.9	-0.5	+0.03
29	+14	+4	-0.3	+3.3	-1.2	+0.07	+33	-22	-0.9	+2.8	-0.7	+0.02
30	+11	-12	+1.2	+6.8	+0.2	+0.07	+23	-60	+0.2	+6.2	+0.7	+0.03
31	+13	-1	-2.6	+2.7	-1.2	+0.01	+26	-33	-3.3	+2.2	-0.8	-0.03
32	-9	+127	-2.4	+1.8	+0.4	-0.01	-28	+80	-3.1	+1.7	+0.4	-0.05
34	+21	+265	-1.2	-4.0	-1.9	+0.09	+55	+320	-0.5	-4.1	-1.7	+0.03
35	+8	+219	-1.0	-0.2	-0.4	+0.07	+21	+240	-0.8	-0.3	-0.4	+0.02
36	-27	+138	-2.9	-1.8	+0.5	+0.05	-26	+250	-0.9	-1.3	-0.1	-0.01
37	+37	-16	+0.6	+2.3	-0.9	+0.05	+52	-96	-0.7	+1.7	-0.3	-0.01
38	+18	+16	+2.6	+1.6	-0.2	+0.08	+20	-53	+1.5	+1.2	+0.2	+0.03
39	+33	+183	-2.3	+3.4	-0.7	+0.06	+75	+217	-2.0	+3.0	-0.3	+0.01
40	+16	-124	+4.5	+0.6	0.0	+0.06	-11	-275	+2.4	0.0	+0.4	+0.02
41	+42	-171	+1.5	+3.5	-0.5	+0.02	+46	-284	-0.5	+2.5	+0.2	-0.02
42	-164	+20	-3.6	-0.4	+1.3	+0.08	-241	+37	-2.9	+0.8	+1.1	+0.03
43	-178	+17	-1.2	-3.9	+2.1	+0.08	-276	+24	-0.6	-2.5	+0.7	-0.03
44	-119	+12	-0.6	-4.6	+1.1	+0.08	-191	+18	-0.2	-3.6	+0.1	+0.03
46	-122	+12	-3.0	-0.5	+2.2	+0.07	-204	+25	-2.7	+0.5	+1.2	+0.02
47	+12	+8	-3.6	-2.0	-0.8	+0.06	+19	+18	-3.5	-2.0	-0.7	+0.01
48	-125	+11	-4.0	+3.6	+3.5	+0.07	-216	+26	-3.8	+4.7	+2.5	+0.02
51	+156	-4	+0.3	+3.6	-2.4	+0.02	+267	-14	-0.1	+2.2	-1.1	-0.02
52	+12	+5	-1.4	+2.5	+0.3	+0.04	+21	-6	-1.4	+2.4	+0.4	-0.01
53	+50	-4	+3.0	+0.9	-0.5	+0.04	+77	-20	+2.7	+0.5	-0.1	-0.01
54	+48	+7	-1.3	+3.1	-0.2	+0.08	+76	+11	-1.3	+2.8	+0.2	+0.03
56	-122	+103	-7.1	-2.4	+2.7	+0.05	-195	+179	-5.3	-0.6	+1.2	-0.01
57	-31	+88	-8.7	+1.0	+0.4	+0.08	-27	+191	-7.1	+1.6	-0.1	+0.02
58	-13	+44	-1.9	-1.2	0.0	+0.09	-18	+76	-1.4	-1.0	-0.2	+0.04
59	-6	+63	-5.7	-0.5	-0.2	+0.10	+1	+140	-4.6	-0.2	-0.4	+0.04
60	-11	+46	-4.8	-0.8	0.0	+0.05	-15	+93	-4.2	-0.6	-0.2	0.00
61	-31	+57	-5.7	-0.2	+1.5	+0.06	-70	+123	-4.8	+0.3	+0.9	+0.01
62	-72	+46	-3.6	-0.5	+3.7	+0.03	-168	+87	-3.0	+0.5	+2.6	-0.02

residuals yielded the RMS estimate of 0°.057 (205") for an ARTEMIS azimuth. It should be noted with emphasis that there were no large outliers among the ARTEMIS range-azimuth data; however, it was noted that the azimuth residuals were overwhelmingly positive.

With the above-specified standard errors, the six observations of each data point were used in a least-squares solution which produced the respective adjusted positions of the ARTEMIS mobile antenna unit. Using these adjusted positions, the process of computing residuals was repeated and new, more accurate estimates of the standard errors affecting the TRISPONDER and ARTEMIS measurements were obtained. The entire process was then iterated, using the same standard errors for the theodolite observations and the new standard error estimates for the TRISPONDER and ARTEMIS data. The residuals produced by the two adjustments are tabulated on the following page.

The symbols used in the heading of the foregoing table of residuals have the following meaning:

LAZ -- Left theodolite azimuth
RAZ -- Right theodolite azimuth
LDN -- Left Del-Norte TRISPONDER range
RDN -- Right Del-Norte TRISPONDER range
RNG -- ARTEMIS range
AZ -- ARTEMIS azimuth

To reiterate, the first adjustment was performed using theodolite intersection observations with standard errors as shown in TABLE V, TRISPONDER ranges with standard error of 5.8m, ARTEMIS ranges with standard error of 2.8m, and ARTEMIS azimuths with standard error of 0°.057 (205"), with the objective of obtaining improved accuracy estimates for the TRISPONDER and ARTEMIS measurements based on the resulting residuals. The aggregate of the residuals of the left and right TRISPONDER ranges produced a new RMS accuracy estimate of 2.9m, and the set of residuals of the ARTEMIS ranges produced a new RMS accuracy estimate of 1.5m.

The residuals of the ARTEMIS azimuth, however, exhibited a definite systematic effect, with a non-trivial sample mean of +0°.053 (+191") given its standard deviation of 0°.027 (97"). This is a rather puzzling development, as the constant measurement error in the ARTEMIS indicated azimuths, determined to be +0°.02 by both the initial and terminal static calibrations, was removed by applying the -0°.02 calibration correction to all ARTEMIS azimuth data. Since the sign of this "underway bias" does not change when the course of the survey launch reverses, it is not a manifestation of a lag in tracking. In as far as could be ascertained by inspection of the data, its magnitude seems to be constant for all the underway data points of the test.

The second adjustment was performed using, again, theodolite intersection observations with standard errors as shown in TABLE V, but now using TRISPONDER ranges with standard error of 3.0m, ARTEMIS ranges with standard error of 1.5m, and ARTEMIS azimuths, after applying a +0°.05 (+180") correction, with standard error of 0°.03 (108"). Based on the resulting residuals, the new RMS accuracy estimates of a TRISPONDER range, ARTEMIS range, and ARTEMIS azimuth were determined to be 2.5m, 1.1m, and 0°.024 (86"), respectively. Using the CHI-

SQUARE test with appropriate degrees of freedom (88 for the TRISPONDER data, 44 for the ARTEMIS data), the a-posteriori one-sigma accuracy estimates were found to be essentially equivalent to the corresponding, more conservative a-priori one-sigma accuracy estimates of 3.0m, 1.5m, and 0°03 (95 percent cofidence level).

RESULTS

Based on the data acquired in this test, the following statements concerning the accuracy of the ARTEMIS range-azimuth microwave positioning system can be supported:

1. The ranges indicated by the ARTEMIS system tested (at 11.5-12.5Km) had a +3.4m constant measurement error and a one-sigma dispersion of 1.5m.

2. The azimuths indicated by the ARTEMIS system tested had a +0°02 (+72") constant measurement error, an unexplained -0°05 (-180") "underway bias" error, and a one-sigma dispersion of 0°03 (108").

Aside from the puzzling "underway bias," which will be further speculated upon in the next section, it is of interest to note that the one-sigma dispersion values of both the ARTEMIS range and azimuth determined by this test are identical to the two-sigma accuracy estimates listed among the system's specifications by the manufacturer. To be true, in this test the ARTEMIS system operated under close to extreme conditions of range, with signals grazing the predicted radar horizon. It is possible that, at lesser ranges and/or under better signal propagation conditions, the accuracy of the system could in fact be better.

UNDERWAY BIAS IN ARTEMIS AZIMUTH

The "underway bias" isolated in the ARTEMIS azimuth data (see ANALYSIS OF THE TEST DATA and RESULTS) points toward a possible area of concern and clouds somewhat an otherwise brilliant performance by the ARTEMIS system. The main concern stems from the fact that this bias, not being present in the data at the usual static calibrations, cannot be readily detected and monitored, as accurate calibrations underway are rather impractical.

Until this bias is eliminated or at least understood and the limits of its magnitude reliably known, one can only speculate whether it is equipment-specific, with different ARTEMIS units having different bias, whether it is range (i.e., signal strength) dependent, whether it is always of the same sign or, in the true sense of a bias, whether it is constant within a sample but random between samples, and above all, whether 0°05 is a representative value of it, or can it assume much larger values. Note that at a range of 12Km, 0°05 of azimuth bias translates into a systematic shift of 10.5m in the position of the survey vessel.

ARTEMIS AND THE HYDROGRAPHIC ACCURACY STANDARD

Aside from operational considerations (see THE ARTEMIS SYSTEM and RADAR HORIZON), the suitability of the ARTEMIS positioning system for hydrographic applications, from the point of view of accuracy, can best be illustrated by showing the limits within which the system is capable of meeting the Hydrographic Accuracy Standard.

The Hydrographic Accuracy Standard (Ref. 1, p. 1-4) requires that "The indicated repeatability of a fix (accuracy of location referred to shore control) in the operating area ... seldom exceed 1.5mm at the scale of the survey." This is further interpreted to mean that the error limit specified may not be exceeded in more than 10 percent of the fixes, i.e., that the positioning system used must be that accurate at the 90 percent probability (1.645 sigma) level.

Since the accuracy of the ARTEMIS position fix is range-dependent, the following table shows the limiting ranges from the shore station up to which the system will meet the Hydrographic Accuracy Standard (HAS) for each of several likely hydrographic survey scales. Two sets of limiting ranges are shown, one for azimuth sigma of 0°.03 on the assumption that the "underway bias" can be eliminated, and the other for azimuth sigma of 0°.06 on the assumption that the "underway bias" is random between samples and that 0°.05 is a one-sigma estimate of it.

TABLE VII
MAXIMUM RANGE AT WHICH ARTEMIS MEETS HYDROGRAPHIC ACCURACY STANDARD
(d = one-sigma position fix displacement limit)

SCALE	HAS	d	AZIM SIGMA 0°.03	AZIM SIGMA 0°.06
1: 1,000	1.5m	0.9m	*1.4Km (0.8NM)	*0.9Km (0.5NM)
1: 2,000	3.0m	1.8m	3.4Km (1.9NM)	1.7Km (0.9NM)
1: 5,000	7.5m	4.6m	8.6Km (4.6NM)	4.3Km (2.3NM)
1:10,000	15.0m	9.1m	17.2Km (9.3NM)	8.6Km (4.6NM)
1:20,000	30.0m	18.2m	34.4Km (18.6NM)	17.2Km (9.3NM)

*Achievable with enhanced range accuracy in "SHORT" mode.

DEL-NORTE TRISPONDER AND THE HYDROGRAPHIC ACCURACY STANDARD

For comparison purposes, the same type of information provided for the ARTEMIS system in the preceding section is given here for the much-used Del-Norte TRISPONDER system. While the operating range of the TRISPONDER system is limited only by the radar horizon and null zone considerations, the accuracy of a TRISPONDER position fix is critically dependent on the angle of intersection of the two ranges at the survey vessel. The limiting values of this intersection angle may be computed by the following formula, derived by the author:

$$\cos(I) = \pm(d^2 - c^2)/\sqrt{(d^4 + c^4)}$$

where:

$$c = \sqrt{(s_1^2 + s_2^2)/2}$$

and: I = max and min intersection angle at the survey vessel
d = one-sigma position fix displacement limit
c = circular standard error (CSE) of the TRISPONDER fix
s_1, s_2 = standard errors of the TRISPONDER ranges

Although the standard error of a TRISPONDER range measurement (both P1 and P2) was shown by this test to be 3 meters, such accuracy can be expected of the TRISPONDER system only under ideal conditions and over a short period of time (e.g. not more than two hours). Even then, as during this test, occasional spurious range indications must be expected. Aside from these interference-caused "jumps," experience has shown that the typical TRISPONDER performance is more properly characterized by a standard error at least twice as large, i.e., of the order of 6 meters.

The following table shows the limiting values of the range intersection angle at the survey vessel for which the Del-Norte TRISPONDER system will meet the Hydrographic Accuracy Standard (HAS). Two sets of the limiting intersection angle values are shown, one for range sigma of 3 meters, and the other for range sigma of 6 meters.

TABLE VIII
MAXIMUM AND MINIMUM INTERSECTION ANGLES
BETWEEN WHICH TRISPONDER MEETS HYDROGRAPHIC ACCURACY STANDARD
(d = one-sigma position fix displacement limit)

SCALE	HAS	d	RANGE SIGMA 3m	RANGE SIGMA 6m
1: 1,000	1.5m	0.9m	*	*
1: 2,000	3.0m	1.8m	*	*
1: 5,000	7.5m	4.6m	58°1 - 121°9	*
1:10,000	15.0m	9.1m	27°6 - 152°4	58°8 - 121°2
1:20,000	30.0m	18.2m	13°5 - 166°5	27°6 - 152°4

*Required accuracy not attainable by the TRISPONDER system.

CONCLUSIONS AND RECOMMENDATIONS

The ARTEMIS is an extremely well engineered microwave range-azimuth positioning system with a great potential for application to hydrography. Provided that the "underway bias" problem can be satisfactorily resolved, the ARTEMIS system is ideally suited for large-scale surveys at short-to-medium ranges (see TABLE VII), in which capacity it would fill a long-existing void, as no other electronic positioning system used by the National Ocean Survey is capable of delivering the required accuracy.

During this short test, under purposely forced marginal operating conditions, the ARTEMIS system performed flawlessly, in sharp contrast to the Del-Norte TRISPONDER system which, even under optimum operating conditions, exhibited temporal instability and interference-caused spurious range indications. The design of the ARTEMIS system promises to eliminate most, if not all, of the familiar and frustrating interference problems which plague the microwave positioning systems used so far by the National Ocean Survey.

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CDR PFEIFER: This completes my presentation.

I will now try to answer any questions.

MEL GRUNTHAL, NOAA: Vik, what happens if a microwave length is broken, say, by a ship passing between the shore and the stations?

How long does it take to search it and lock back on?

CDR PFEIFER: The equipment goes automatically into a search mode, and as soon as the line of sight is cleared, it reestablishes lock within one revolution of the antenna.

It's real impressive.

ADAM J. KERR, Canadian Hydrographic Service: Working with the Mini-Ranger system, we have been experiencing some difficulties with range holds recently, and particularly the depreciation of accuracy in the area of the range holds.

Do you have range holds with ARTEMIS?

CDR PFEIFER: We did not experience any during this test. Of course, it was not likely that we would have them at such a range. The range holds, if they are new zones which we are referring to, they are pretty close to the shore antenna, and this occurrence, or likelihood increases with the elevation of the antenna.

The system is a microwave system, and, of course, it is liable to that kind of a problem.

What it perhaps is an improvement over the Mini-Ranger system and the Del Norte system, in that it utilizes the horizontal wave guide highly directional antennas, whereas the Mini-Ranger and the Del Norte have wide beam antennas at the shore station, and omni-directional antennas at the mobile station, so they are picking up reflected signals from side objects, ships passing in the distance and so forth, causing destructive interference. We have a lot of problems using Mini-Ranger in Cook Inlet with reflections coming from off-shore drilling rigs, far into the distance, which we wouldn't have suspected. I feel that that sort of interference would be completely eliminated by the system.

MR. KERR: Would you explain again how you set it on the reference in the first instance? How is that done?

CDR PFEIFER: The system has a telescopic attachment, the shore station antenna, through which you sight on an azimuth reference object.

We used a control point, which was a radio tower, and sighted on it. We know what the azimuth is. The azimuth is dialed into the equipment, and from

that point on, any deviation from that direction is covered by the equipment.

MR. KERR: And a first step in the setting-up procedure then is to establish a zero reading, electronic reading on that, as well as the sighting; is that correct? That is your zero reference point?

CDR PFEIFER: I don't understand what you mean by zero reference point.

MR. KERR: You are measuring angles from your reference?

CDR PFEIFER: Yes.

MR. KERR: So that is part of the setting-up procedure?

CDR PFEIFER: Yes.

One thing that I failed to mention is that oftentimes we can increase the operating range with a microwave system by elevating the antenna on top of a mast, while this is impossible with this system, because it requires that it be at the height of eye, so that you can sight through a telescope on a referenced object.

Also, it would be impossible to prevent any torsion in a mast, which would, of course, introduce an error into the azimuth measurements.

LCDR ALAN J. PICKRELL, NOAA Ship FAIRWEATHER: What about a change in the vertical attitude of the directional antennas, as far as the launch moving toward or away from the shore staton, at close proximity?

CDR PFEIFER: We did not experience any problem. The shore station antenna was always horizontal. The mobile antenna was mounted on the forecastle of the Jensen. And, as you all know, the Jensen Launch, a type-one launch, acquires a rather pronounced settlement squat once it gets under way. This was one of my ideas originally to explain for this under-wayway bias: how come at a standstill calibration we don't see any bias, and as soon as the launch gets under way, we see this five-hundredths of a degree bias all of a sudden.

Perhaps that still could be -- of course, I'm not an electronics expert -- that the relative inclination of the two loads may cause the electronic match-up of the two loads to be consistently off to one side.

I don't know if I answered your question.

LCDR PICKRELL: The antennas do move up and down?

CDR PFEIFER: Negative. They move only in azimuth. They only swing. Perhaps if this is a problem, they could be mounted in a gimbals or gyro stabilizer.

RADM TAYLOR, N.O.A.A., Retired: First I would like to commend Commander Pfeifer for his fine treatment of this test. When I was in Canada last year, I saw the demonstration, and I had some intuitive suspicions about the accuracy

of the azimuths -- I was on the shore station of this equipment, and I held the wave guide and still sighted the launch with the telescope theodolite, and you could push very hard on that wave guide, and you got no movement at all. It really locked on very tightly. And for that reason, I worked with Admiral Lippold to see if we could make a definitive, objective test, and since they had an office down at Texas, I knew Commander Pfeifer would do an excellent job in getting this worked out, and I think this is one of the few times I've seen a new piece of equipment get tested very quickly and in two weeks have the final report.

Thank you.

CDR PFEIFER: Appreciate the fine comments, Admiral.

Any further questions?

LCDR YEAGER: Based on your experience, both with programming and this system, what type effort, or how significant would you assume the effort to be to develop a software program to use the system with our standard hydroplot?

CDR PFEIFER: Well, any sort of piece of software is a major undertaking. I understand that we have in progress the preparation of software to handle optically observed manually recorded range azimuth data, like observing with theodolite, and ranging instruments.

I defer to Jack Wallace to answer this question.

JACK WALLACE, Marine Operations: We have a contractor writing a real time range azimuth program.

I would think the only problem with this would be the hardware interface. It has a BCD, or RS-232 on-board output connector?

CDR PFEIFER: It's a BCD to output, I'm told.

MR. WALLACE: It would be relatively simple, I would think.

LCDR YEAGER: Thank you.

CDR PFEIFER: My only regret is that we don't have half a dozen of these on each coast.

LCDR YEAGER: Thank you very much Commander Pfeifer.

CANADIAN AERIAL HYDROGRAPHY SYSTEMS

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ABSTRACT

The Canadian approach to aerial hydrography involves two techniques that, until now, have been operating in parallel. The Photo/Lidar system is unique since it combines photogrammetric and laser bathymetry techniques and relies on information from an inertial navigation system (INS) to overcome the problem of incomplete stereo models over open water. This approach has yielded a depth accuracy of ±1m (2σ) and a positioning accuracy of ±1m. The Photo Interpretation approach yields reliable shoreline, hazard identification and shallow water contours by a less rigorous technique. The two methods will be integrated in the near future to reduce Photo/Lidar processing time and costs.

1.0 INTRODUCTION

Surveying shallow inshore waters accounts for a large percentage of the costs and time spent on conventional hydrographic surveys. The Canadian Hydrographic Service (CHS) has been examining aerial photogrammetric techniques and laser bathymetry in search of a viable alternative to such surveys. Two separate approaches, an integrated Photo/Lidar (Light Detection and Ranging) system and Photo Interpretation techniques have been investigated in recent years.

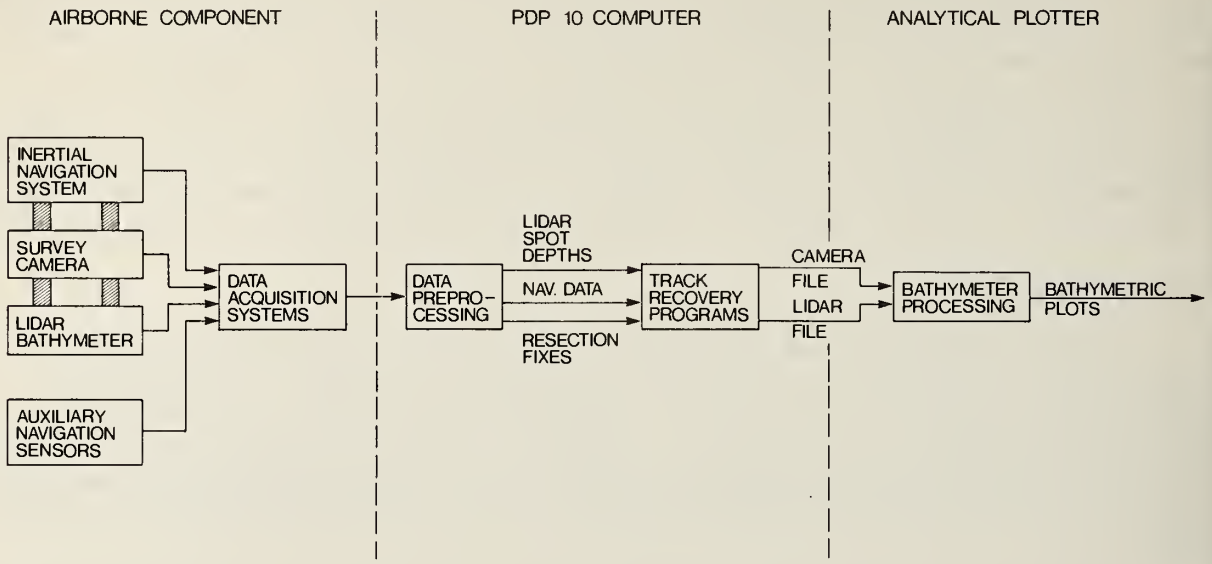
The greatest attention has been focused on a unique integrated Photo/Lidar system which obtains color aerial photography and Lidar bathymeter depths while using a Litton Inertial Navigation System (INS) to measure aircraft position and attitude at the time of each camera and Lidar firing. Following the mission the INS data are used to set up stereo models on an analytical plotter where spot depths are measured photogrammetrically and integrated with the depths from the profiling Lidar bathymeter. The result is a plot of shoreline features and spot depths.

The Photo Interpretation process is a more subjective approach which combines limited ground truthing (sounding profiles, bottom samples, etc.) with bottom pattern data interpreted from aerial photographs. A rectified (controlled) mosaic acts as a base on which to orient the photographs and display the interpreted data. The result is a shoreline plot showing hazards and shallow water contours. This approach is being integrated with the Photo/Lidar method in an attempt to improve the processing efficiency of the aerial hydrography program.

The Photo/Lidar system and the Photo Interpretation method are discussed and the results of the 1979 projects presented. The preliminary results of the 1980 aerial mission and areas of future investigation are also addressed.

2.0 PHOTO/LIDAR SYSTEM

The integrated Photo/Lidar system was assembled by P. A. Lapp Ltd. (PALL), Toronto, for the 1979 pilot project which was carried out on the St. Lawrence River near Gananoque, Ontario. The system is a combination of the Canada Centre for Remote Sensing (CCRS) Photo bathymetry and Lidar bathymeter systems arranged as illustrated in Figure 1. The structure and operation of the three major subsystems are outlined in the following paragraphs.



2.1 Airborne Subsystem

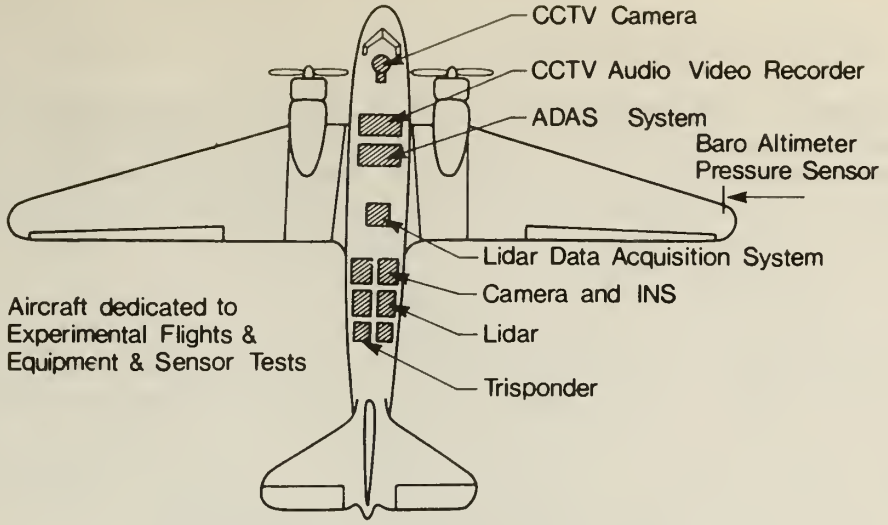
The main airborne components of the aerial hydrography system consists of the following equipment mounted in CCRS' DC-3 aircraft C-GRSA (Figure 2):

- Aerial Survey Camera - Wild RC-10
- Lidar Bathymeter System (laser)
- Inertial Navigation System (INS) - Litton LTN-51
- Airborne Data Acquisition System (ADAS).

The following auxiliary sensors contribute additional information:

- Microwave Ranging System - Del Norte Trisponder
- Barometric Altimeter - Garrett AF TS - 23
- Radar Altimeter - Honeywell Y67500

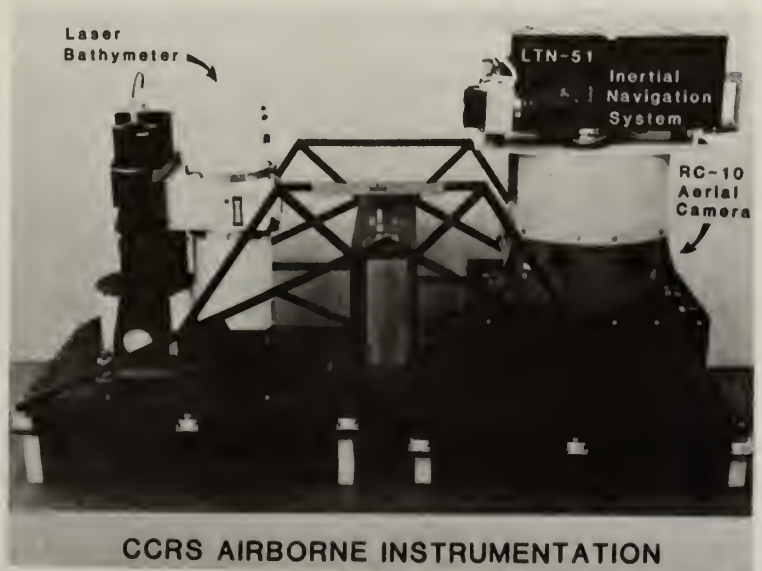
Some of the characteristics of the components of the airborne package are given in the following paragraphs.



Dakota C-GRSA

2.1.1 Aerial Camera and Lidar Bathymeter

The Wild RC-10 aerial survey camera has a 153 mm focal length lens and a 23 cm x 23 cm format. The camera is attached to a bridge structure (Figure 3) which also supports the Lidar bathymeter and maintains the alignment of the optical axes of the two sensors. The Lidar system is a profiling bathymeter that is composed of a laser transmitter, an optical/electrical receiver and a data recording system. The transmitter is a frequency doubled Nd:YAG laser that delivers up to 10 MW peak pulse power at 532 nm (green) and 15 MW peak pulse power at 1064 nm (infrared). The 532 nm wavelength receiver acquires depth data while the 1064 nm wavelength receiver picks up surface returns (slant ranges) at a maximum pulse repetition rate of 10 Hz.



CCRS AIRBORNE INSTRUMENTATION

2.1.2 Inertial Navigation System

A gimbolted Litton LTN-51 inertial navigator is hardmounted to the aerial camera and is used to measure the position and attitude of the camera and Lidar bathymeter in real time. This modified unit is equipped with high resolution dual-speed resolvers which enable platform indicated attitude to be read to a resolution of ±5 arc seconds and an accuracy of approximately ±60 arc seconds.

2.1.3 Airborne Data Acquisition System

The ADAS system, which was built for CCRS, provides the interface between the airborne sensors and the ground processing components of the aerial hydrography system. It formats, time stamps and records all of the data on high speed analog tape. The data recorded by ADAS are converted post-flight to standard Johnson Space Center non-imagery (JSC-NIM) format which is the input format to the track recovery software package.

2.1.4 Auxiliary Sensors

The INS supplies data that are used to provide coordinates for Lidar depths as well as the orientation parameters of each aerial photograph. These parameters are used to set up stereo models on an analytical plotter. These INS data are not sufficiently accurate on their own, thus data from auxiliary sensors are used to correct the INS generated camera parameters (2).

2.2 Track Recovery System

Following the mission, the INS and Lidar data are stripped from the ADAS tapes and written to disc for processing. The Lidar returns are displayed manually and edited to form a file that contains the time, slant range and slant depth measurement for each laser firing. The position, velocity and attitude data from the INS are processed together with the data from the auxiliary sensors to arrive at precise estimates of the in-flight position and attitude parameters of the camera and lidar sensors.

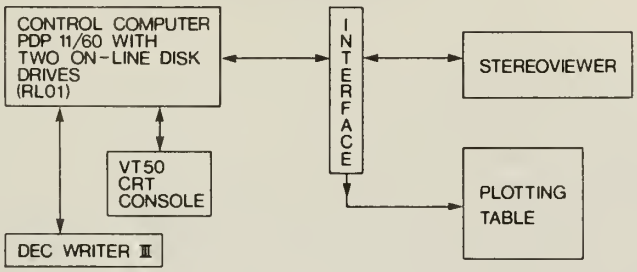
An extensive track recover software (TRS) package was developed to perform the above function. The package employs recursive, optimal estimation algorithms - A Kalman filter and optimal smoother (See eg. 3) - which compute minimum-variance estimates of the inertial system error state using a high order mathematical model of the sensor error characteristics (2). Further details are contained in (1,4).

The output of the TRS package can be described as follows:

1. Flight Profile Parameter File containing the time-histories of aircraft position, velocity and attitude parameters (2).
2. Camera File containing the position and attitude of the RC-10 camera at each firing time referenced to an earth-fixed (geodetic cartesian) coordinate system (2).
3. Lidar File containing selected lidar spot depths corrected for slant angle and refraction effects and the geographic coordinates of each depth (2).

2.3 Analytical Plotter

The analytical plotter is comprised of a stereoviewing instrument and a plotting table interfaced to a control computer (Figure 4). The operation of the plotter in the hydrographic mode is as follows. The camera file generated by the TRS package provides the camera orientation parameters of the aerial photography. These data are input into the analytical plotter and used to set up stereo models. The depths of bottom features are measured by the operator and a refraction correction applied in real time. The measured depths are adjusted off-line in the computer using redundant depth/height information provided by the lidar spot depths and water-line points. The adjusted depths are then plotted at the required scale using the flatbed plotter.

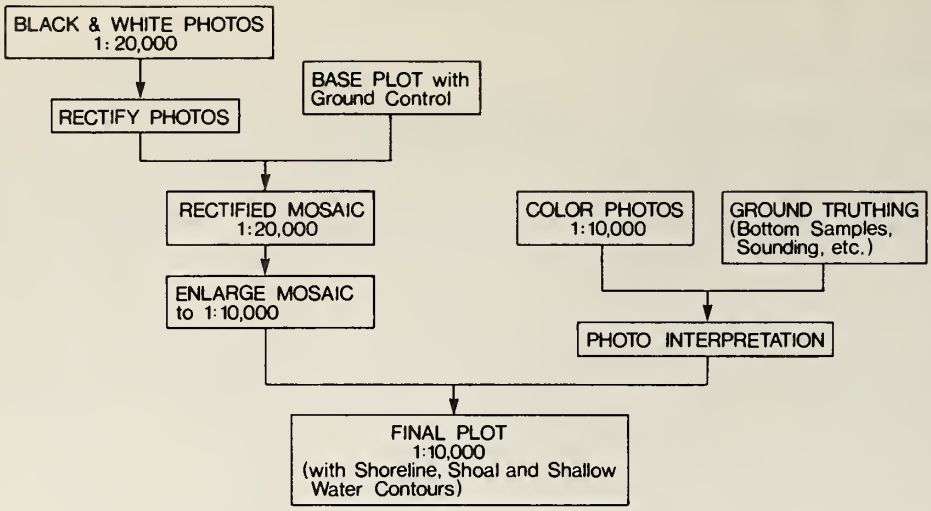


3.0 PHOTO INTERPRETATION

A method of extracting hydrographic data from aerial photography using photo-interpretive techniques was developed by a Toronto firm, Hunter and Associates Ltd. This process was used in 1979 to produce shoreline and shallow water bathymetry plots of the North Channel area of Lake Huron. The basic steps of the photo interpretation process are outlined in Figure 5 and explained in some detail in the following paragraphs.

3.1 Ground Truthing

This approach requires limited field work. Depth profiles are obtained between identifiable features on the area photography (eg. point to point) in selected areas and bottom samples obtained at locations identified on the photography. Some geological information about the area and shoreline is obtained and the photo interpreter requires several flights over the area to become familiar with the general features of the region.



3.2 Rectified Mosaic

A rectified mosaic of the area is prepared, normally from smaller scale photography than that used for the photo interpretation process. This mosaic acts as a base plot which provides relative positions of shoreline, hazards and other identifiable features. The photographs used in the photo interpretation process are orientated to the mosaic and this mosaic also serves as a document on which the resulting information is portrayed.

3.3 Airphoto Interpretation

This approach is based on the recognition of airphoto pattern elements and the elevational relationships of these pattern elements to chart datum. Pattern element analysis is supplemented by stereoscopic viewing, field reconnaissance and depth profiles. A thorough knowledge of coastal processes, both physical and biological, is a prerequisite for application of this technique to hydrography. A field survey and office interpretation team would usually consist of an airphoto interpreter experienced in geomorphology supported by a coastal marine biologist. Once the airphoto interpreter becomes familiar with the area and the relationship of the pattern elements with chart datum, it is possible to quickly draw shallow water contours and plot shoals.

4.0 RESULTS (1979)

Both 1979 projects yielded encouraging results but they failed to conclusively demonstrate the viability of aerial hydrographic techniques as a production survey tool. The Photo/Lidar pilot project failed to meet the depth accuracy standard of CHS (±.3m in depths $\lesssim$20 m) and did not clearly identify the means of improving the results. The Photo Interpretation project yielded adequate shoreline plots but was forced to use existing black and

white aerial photography when a contractor failed to obtain the necessary color photography, thus the results may not reflect the true potential of this technique. Some of the results obtained from these projects are given in the following paragraphs.

4.1 Photo/Lidar System

A total of nine plots at a scale of 1:5000 were produced from the St. Lawrence River data. These plots were not continuous but from selected areas and each corresponded to one stereo model and covered an area of approximately 3 km^2. Based on the belief that the Lidar depths were more reliable due to the superior penetration power of the Lidar bathymeter, photo depths in the vicinity of Lidar depths were adjusted by a least squares algorithm and these adjusted depths plotted.

4.1.1 Coverage and Depths

The coverage and depth penetration of the system was severely limited by water turbidity and dense weed growth. Thus the coverage per model varied from 2% to 40% of the total water area and the maximum depth obtained was 4.4 m with the lidar and 4.2 m photogrammetrically. However, previous tests have shown that depths attained by the Lidar are normally two to three times the depths obtained by photogrammetric means.

4.1.2 Depth Accuracy

The plots prepared by the pilot project were compared to field sheets of the area. The contractor selected depths at random and compared them with the depths on the field sheet. A total of 357 depths were compared and the depth differences found to have a standard deviation/RMS value of .65 m. An assumption was made that errors in the field sheet depths and interpolation errors would contribute an uncertainty of .5 m to this value, thus the RMS error in Photo/Lidar depths was 0.42 m ($.42 = \sqrt{(.65)^2 - (.5)^2}$). How valid this assumption was remains to be seen but the projected depth accuracies were as follows:

68%	of depth	difference	have	magnitude	$\leq \pm$	.5 m
90%	"	"	"	"	$\leq \pm$	1 m
95%	"	"	"	"	$\leq \pm$	1.5 m

Another interesting conclusion was the fact that the Lidar depths did not appear to be as good as those of the photo system. This was attributed to the high level of water turbidity as well as the dense weed growth that prevented the Lidar pulse from reaching the true bottom. Approximately 100 Lidar returns were compared to the field sheet depths with 56% agreeing within ±.5 m and 72% within ±1.0 m. (2)

4.1.3 Positioning Accuracy

To analyze the positioning accuracy of the system, photogrammetrically measured coordinates of control points were compared to the ground values. A total of 9 measurements were made on 5 different targets and the results

indicate that the total horizontal RMS deviation was $\leq$.75 m. On the basis of this and other tests the accuracy figure of 1 m RMS was arrived at for a flying altitude of approximately 1500 metres. This corresponds to .2 mm RMS error at the 1:5000 plot scale. The error in the plotting instrument was found to be approximately .25 mm, thus the maximum RMS plotting error, computed as the sum-root square of the RMS coordinate and plotter errors, was estimated to be less than .35 mm at this scale.

4.1.4 Other Results

Several other results of the pilot project are worthy of note since they contributed to the accuracy of the system:

- difficulties were experienced with residual parallax when models were set up relying entirely on the orientation parameters from the TRS package.
- the attitude accuracy of the system (±60 arc seconds) failed to meet the requirement of ±30 arc seconds that was calculated to be the maximum allowable error if depths were to be measured to ±.6m (5).
- the microware ranging system proved to be of little benefit where resection fixes could be obtained at the start and end of flight lines.
- cost and time benefits of 4:1 and 5:1 respectively, over conventional methods were claimed. However a fair amount of extrapolation was involved to obtain costs and time necessary to achieve 100% coverage by aerial methods.

4.2 Photo Interpretation

A total of 5 plots containing approximately 160 km of shoreline were prepared by the Photo Interpretation process. The base plots were supplied by CHS and the plots containing shoreline, hazards to navigation and shallow water contours were prepared by the process outlined in Section 3.

These plots were used to complement a conventional hydrographic survey of the area during the 1980 field season. This survey party was most impressed by the number of hazards (rocks, shoals, etc.) positioned on the plot, which greatly simplified the task of locating, positioning and obtaining a depth on these hazards. The shoreline detail was very good and the fit of the shoreline as good as or better than any photogrammetric plot used by the Hydrographer-in-Charge in previous years.

Contours, to four metres, agreed reasonably with those of the field sheet where there was a definite slope to the bottom but less well in extensive flat, shallow areas. A paper by the contractor indicates that tests to date show:

- the water line is more accurate by airphoto interpretation than by conventional field means.
- the two metre contour can be followed within ±.5 m of the true depth depending on shoreline characteristics (±.2 m in arctic tests).
- the four metre contour can be drawn to an accuracy of ±1 m.

- the six metre contour (if visible) can be drawn to ±1.5 m accuracy depending on the amount of control available (6).

It should be noted that the above accuracies have not been field verified over extensive areas.

5.0 AERIAL MISSION (1980)

A 1980 aerial mission was planned to seek answers to such questions as; cost to do complete areas, the percentage of water area covered, the overall agreement of the final document with field sheets and the logistics of carrying out such an operation. The integration of the Photo/Lidar and Photo Interpretation approaches was also planned in an attempt to reduce the processing costs of the Photo/Lidar approach.

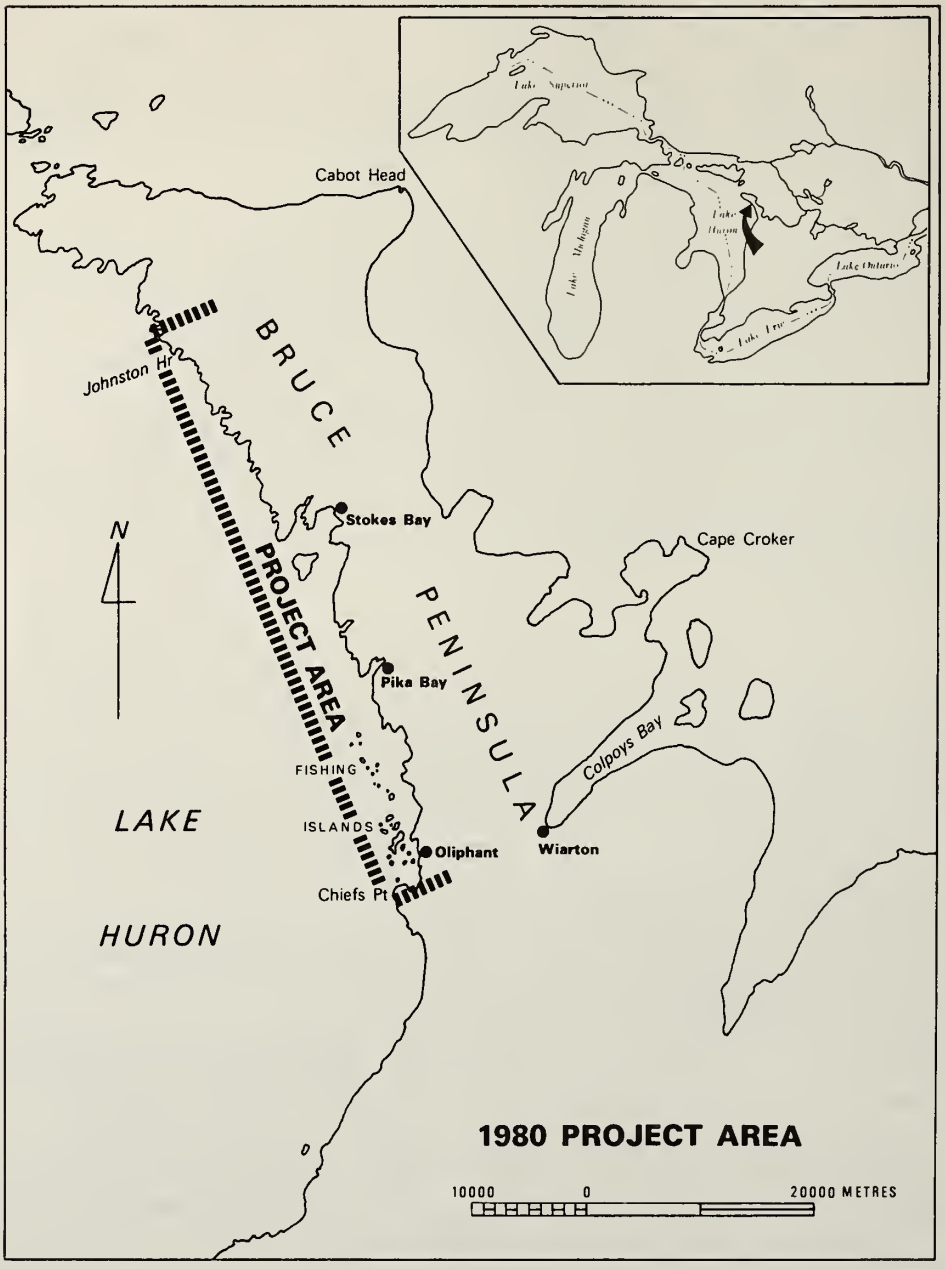
This mission was carried out in Lake Huron along the western shore of the Bruce Peninsula (Figure 6). The aerial photography and Lidar bathymeter data were obtained by CCRS aircraft equipped with basically the same sensors as were used in 1979, with two exceptions. The Del Norte Trisponder system was not included and a second inertial system was added (Honeywell H478H Strapdown). Color photography and Lidar depths were obtained from an altitude of 1500 m (AGL) while black and white photography and a Multi Spectral Scanner were flown from 3000 m (AGL). The quality of this data appears excellent with depths of 7 m being measured photogrammetrically and 26 m obtained with the Lidar in preliminary evaluations.

6.0 FUTURE ANALYSIS

Several areas requiring further investigation have been identified as a result of the 1979 and 1980 aerial missions. Some of the ongoing and planned investigations are outlined in the following list:

- if possible, obtain the evaluation of the strapdown inertial system from Defence Research Establishment Ottawa (DREO) and determine if its inclusion in the sensor package will improve accuracies.
- integrate Photo/Lidar and Photo Interpretation by using Photo/Lidar data of selected areas in the Photo Interpretation process in lieu of conventional sounding profiles.
- investigate measuring only selected spot depths (shoals, obvious deeps, etc.) photogrammetrically and having the plotter operator interpret contours between the spot depths.
- prepare a 1:5000 scale conventional field sheet of an area which will be reduced to 1:10,000 and used for calibration purposes.
- complete the processing of all the 1980 data and draw up 1:10,000 scale field sheets prepared by Photo/Lidar, Photo Interpretation and integrated approaches. Compare these plots to each other as well as the conventional field sheet to arrive at an answer to the Question, "Is 100% coverage with spot depth accuracies of ±1 m as good as profiles with depth accuracies of ±.3m?"
- investigate the accuracy of spot depths measured by the Zeiss Stereocord System and ways to integrate this system with the Photo Interpretation approach.
- evaluate the MSS data for application to hydrography.

- fly a mission in 1981 to exercise the system and gain experience in the various facets of its operation.



7.0 CONCLUSIONS

An operational prototype Photo/Lidar system has been developed for aerial hydrographic surveys. The test results from 1979 are encouraging but at present these results are based totally on data from one project which was conducted in a less than ideal environment. The results CHS obtain from the 1980 Bruce Peninsula data will be an independent verification of the original estimates of accuracies, costs and time benefits.

The Photo Interpretation process has produced results that are very useful in complementing conventional hydrographic surveys. The quality of data supplied by this approach will be evaluated through comparison of final plots with those supplied by Photo/Lidar and conventional techniques. The results of integrating the two approaches will also be evaluated in 1981 and a cost effective hybrid may be identified.

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DISCUSSION

MR. MacDOUGALL: Are there any questions?

LCDR YEAGER: Thanks, Dick. That concludes the formal presentation portion of this session.

INTERPRETATION OF SATELLITE IMAGERY RELATED TO BATHYMETRIC FEATURES

R. A. Arnone (Naval Ocean Research and Development Activity)

(*Color composite imagery is illustrated in B&W.)

Satellite imagery provides a useful technique for interpretation of bathymetric and hydrographic features. With the advent of more recent developmental satellite systems, a multiple approach for interpretation of features can be realized. Additionally, developments with enhancement techniques for processing of satellite imagery have aided the interpreter and extended his ability in understanding coastal processes which ultimately defines hydrographic and bathymetric features.

The exploitation of satellite imagery for updating charts provides a rapid and inexpensive survey technique. Presently these techniques only provide a qualitative estimate of chart accuracy, though quantitative approaches to extracting bathymetry are under research.

This paper is directed at demonstrating satellite interpretation techniques as a tool for updating charts for hydrographic features. Three areas have been selected illustrating specific interpretation and enhancement techniques. Numerous other examples have been selected illustrating specific interpretation and enhancement techniques. Numerous other examples have been found but will not be addressed in this paper. (See Arnone, R. A. et al, 1981 for further discussion.)

CEDAR KEYS, FLORIDA

Cedar Keys, Florida is located on the west coast approximately fifty miles north of Tampa (figure 1). The water clarity in this area is changing constantly as a result of its proximity to the discharge of the dark, tannic rich Suwannee River. LANDSAT data (Multispectral Scanning System) collected over this area was subsampled, computer enhanced and displayed in figure 2b as a color composite of Bands 4, 5, and 7. The composite is similar to a color IR aerial photograph with red signifying land features. This composite was warped to geometrically overlay the hydrographic chart by selecting specific control points as identical land features on both the LANDSAT image and the chart. Figure 2a illustrates the corresponding chart. Note similarities in location and shape of the reefs to the east (Waccasassa Reefs) and to the northwest (Suwannee Reef). Also

note the similarities in positions of various islands and complex shoreline. Similarities in subsurface hydrographic and bathymetric features can also be observed though it is difficult to interpret highly detailed similarities at this pixcel resolution (160 x 120 meters).

A full pixcel resolution (80 x 60 meters) LANDSAT image of Cedar Keys is magnified and similarly enhanced and displayed as a color composite in figure 3b. This image was also warped to overlay a highly detailed chart which is illustrated in figure 3a for direct comparison. Note the similarities in channel location and island position and shape. Subsurface shallow features also are observed as lighter tones in the LANDSAT image. The positions of most of the light tones in the LANDSAT image can be directly related to a shoal area on the chart. However, there are several dissimilar subsurface features. Differences can arise from miss-positioning on the chart resulting from dynamically changing shoal positions or poor selection of control points used for warping the LANDSAT image. In any case, LANDSAT imagery provides a technique to rapidly evaluate whether additional investigations for chart update is required.

LITTLE BAHAMA BANK

An area of Little Bahama Bank located north of Grand Bahama Island and west of Abaco Island was selected as the second area of investigation. In a similar manner as for the Cedar Keys area, a subsample of LANDSAT imagery was computer enhanced and warped to overlay the hydrographic chart of this area. The chart and color composite of LANDSAT imagery (26 March 1977) is illustrated in figure 4a and 4b. Numerous similarities and differences can be seen through comparison. The position and shape of the bordering reef along the northern extent of the Bank is clearly defined in the imagery. The position and shape of the small northern Cays is clearly illustrated. Between the Cays, the subsurface sand fans depicting the dominant current directions also are illustrated by their light blue tonal representations. In the central section, the LANDSAT image illustrates a complex assemblage of dendritic channels which is not displayed on the chart. Note also in the image the presence of numerous elongated white patches in the central area (for example north of Veteran Rock) which have no bathymetric counterpart on the chart. The presence of this large number of unassociated shoals appears to point toward uncharted shoals.

By examination of this same area at an alternate date, LANDSAT imagery appears quite different, though dominant hydrographic features are more pronounced. Figure 5a and 5b illustrate the chart and corresponding color composite LANDSAT imagery for 8 April 1978. Similar subsurface sand fans are well illustrated between the offshore Cays, as are the complex dendritic channels. Notice the large number of elongated white patches are not shown in the imagery. This temperal variation in these white patches is characteristic of "fish whites" or precipitation of calcium carbonate which results as a highly localized, white turbid water. Their occurrence is highly variable and unassociated with hydrographic/bathymetric features. The local currents tend to diffuse this transitory phenomenon in elongated patterns as is observed in figure 3b.

Through comparison of the temporal variation of satellite imagery, a better understanding and interpretation of the coastal processes and hydrographic features can be realized.

A full resolution LANDSAT color composite from 26 March 1977 is illustrated in figure 6. This image is similarly enhanced and warped to overlay the hydrographic chart. Figure 6 shows Stranger and Carter Cays in the northern offshore island chain (see chart figure 3a) and the associated surrounding hydrographic features. Also illustrated are the elongated "fish whites" in the southern section. Notice the hydrographic detail which the imagery shows, especially surrounding Carter Cays. Notice the position of the dark blue channels and lighter blue tones corresponding to sand shoals. Through comparison with the chart for this area more hydrographic information appears to be demonstrated in the LANDSAT image than in the chart.

The exploitation of LANDSAT imagery for demonstrating applications in hydrographic charting has been emphasized thus far; though other satellite systems also exhibit potential. For example, thermal IR imagery from NOAA 5 imagery is illustrated in figure 7. This image is taken in winter where the colder temperatures appear white and the warmer temperatures appear dark. The southern Florida coastline and Bahama area is clearly visible in this figure. The warm Florida Current is illustrated between the mainland and the Bahama Islands. The lighter tone areas in the Bahamas correspond to Little Bahama Bank and the Great Bahama Bank and other shallow water features. Shallow water tends to cool more rapidly than deeper water. These water temperature differences provide the interpreter a technique to use thermal IR imagery as an indicator for shallow water. Note also in this figure that the Tongue of the Ocean located in the southwest section of the image is clearly defined by the dark tone. Exploitation of thermal IR data permits a rapid surveillance technique of assessing the extent of large shallow water areas.

CAPE COD, MASSACHUSETTS

Band 5 of LANDSAT (MSS) scene, 17 July 1974 for the Cape Cod area is illustrated in figure 8. This standard product of the EROS data center aside from illustrating the land features, shows the extent and position of 1. internal wave packets on the northeast portion of the scene and 2. Nantucket Shoals on the southeast portion of the scene. Because of the subtle detail of the internal waves, a color composite of a subsection of the Cape Cod image was enhanced and illustrated in figure 9. Numerous internal wave packets manifest themselves on the sea surface as a series of elongated rough and slick areas. The LANDSAT imagery readily displays these features.

Internal waves are presently undergoing much research in regard to what causes them and where they are most likely to occur. Research has demonstrated that subsurface bathymetric features are associated with producing internal waves to be observed on the surface. (Apel et al, 1976, 1974). Apel et al, 1976

suggests that as the internal wave packets approach a shoaling bottom, the wavelength of the surface slicks increases. Thus by close examination of the wavelengths, the interpreter has a useful technique to estimate bathymetric changes.

The internal wave packets were transferred from the LANDSAT image to the hydrographic chart of the Cape Cod area. (figure 10). The 100 and 50-fathom contour is drawn on the figure for clarity. Internal wave packets on the east appear to align with the 100-fathom contour and their wavelength increases as the bottom shoals. In the central area of the 100-fathom area, a shallow area (approximately 80 fathoms) is encountered. The internal wave packets appear to disseminate from this general shallow area. Note also that the wavelengths are increasing as the shallow area is approached. It should also be noted that there are other locations where internal wave packets are not well associated with bathymetric features and that further research is required for a better understanding. However, the position of internal wave packets suggests bathy-metrically related features and provides an interpretative aid for satellite imagery.

Also illustrated in the color composite of the Cape Cod LANDSAT image (figure 9), are hydrographic features of the Nantucket Shoals. These shoals are located to the east of Nantucket Island as is illustrated in the chart in figure 9. A full resolution color composite of the shoals was computer enhanced and warped to overlay the hydrographic chart. Figures 11a and 11b illustrate the 30-foot contour chart and the corresponding LANDSAT imagery. Because of the distortion between the chart and the image, complete agreement in overlaying the two was not demonstrated. Disagreement results from inadequate selection of control points for geometrically warping the LANDSAT image and inaccuracies in the chart. However, similarities in the shape of the complex "S" shaped shoals can be observed. The light blue coloration in the LANDSAT image results from both 1. bottom reflectance and 2. differences in the sea surface roughness. These characteristics are directly associated with shoal features and are detectable with the LANDSAT system.

The exploitation of other satellite sensors, as it was previously stated, can be directly related to hydrographic feature recognition. Figure 12 illustrates a non-geometrically corrected Synthetic Aperture Radar (SAR) image of the Nantucket Shoals area, which was taken aboard SEASAT. Notice the identical position and complex "S" shaped shoal features as the LANDSAT imagery and hydrographic chart. The resolution of the SAR image provides greater detail of the shoal features in that it is six times that of LANDSAT. Note that the radar only images the sea surface and not the bottom features directly. Present research is underway to glean a better understanding of how the SAR imagery is related to hydrographic features in addition to SAR's response to currents, waves and other oceanographic processes.

CONCLUSION

The three examples presented to illustrate interpretation of bathymetric features using imagery are only several of numerous examples. An understanding of the basic coastal processes and physics of satellite sensors is required to accurately interpret hydrographic features. Satellite interpretation techniques and the extent which satellite imagery can be exploited for charting related activities has not been developed to its potential. As the interpreter becomes more familiar with present satellite imagery he will develop a better understanding of the coastal processes and their relationship with hydrographic features. With development of enhancement techniques, increased resolution, and new sensor systems, satellite applications will continue to augment the interpretation of hydrographic features.

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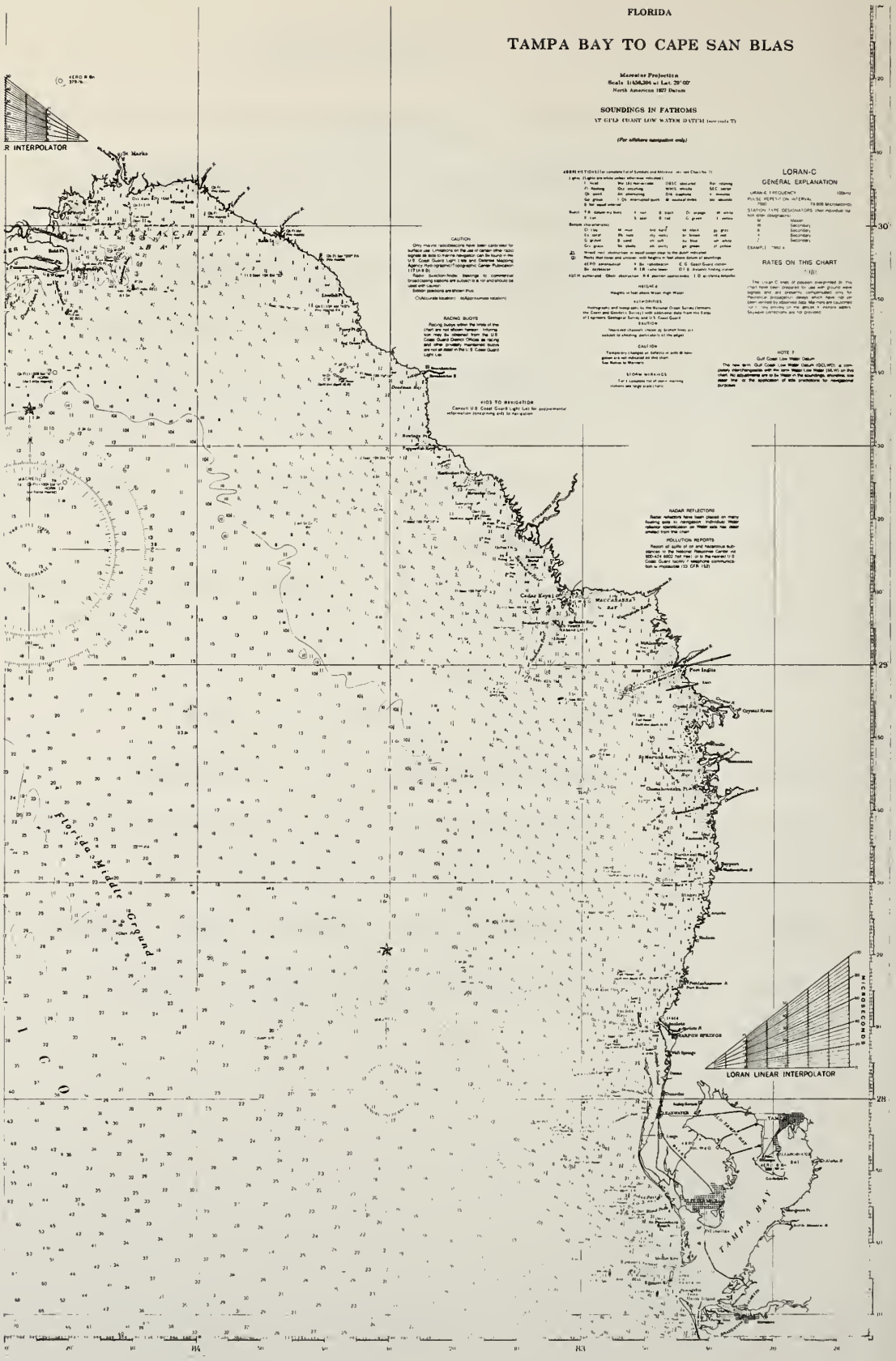
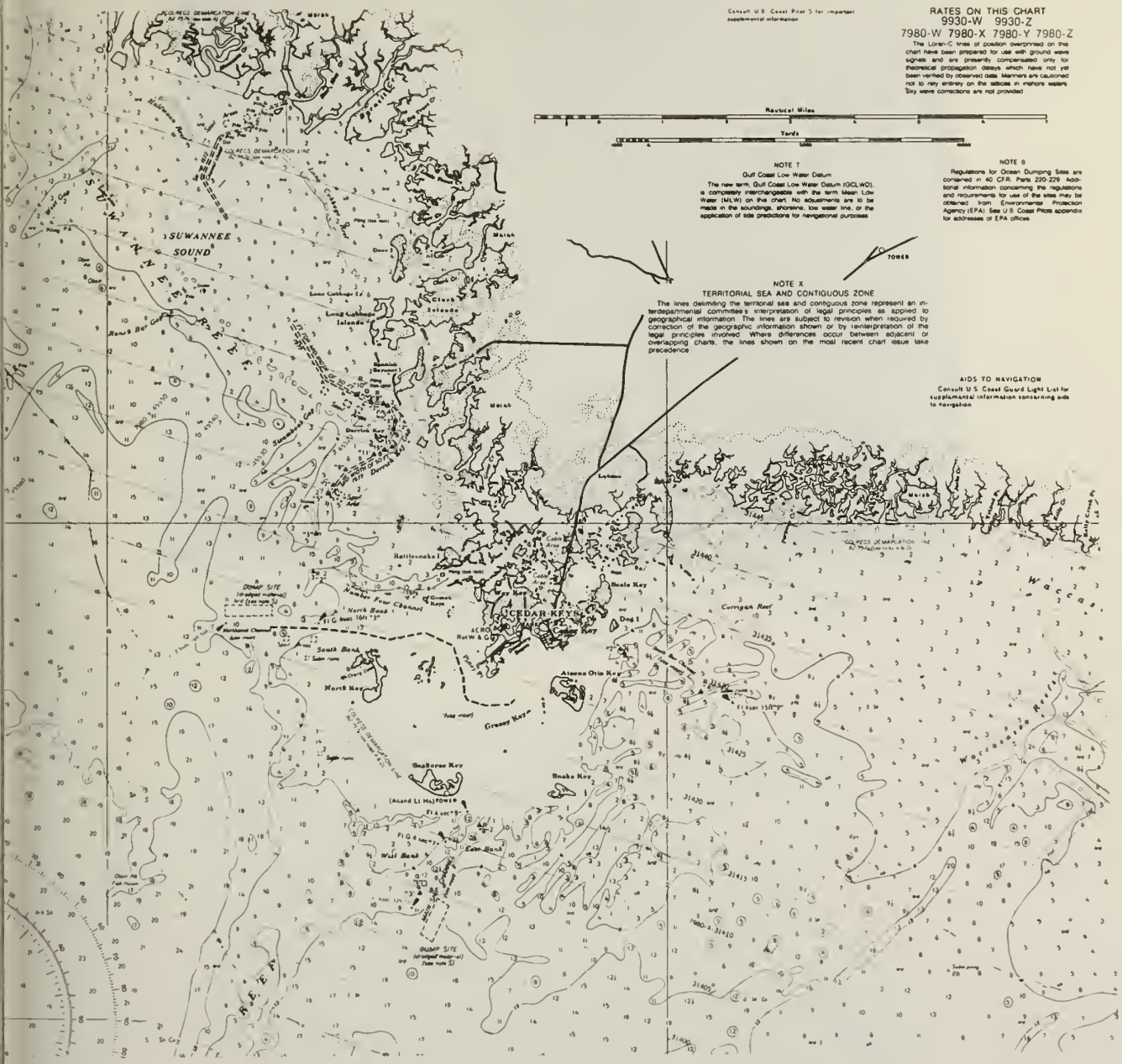


Figure 1. Location of Cedar Keys on the West Florida Coast



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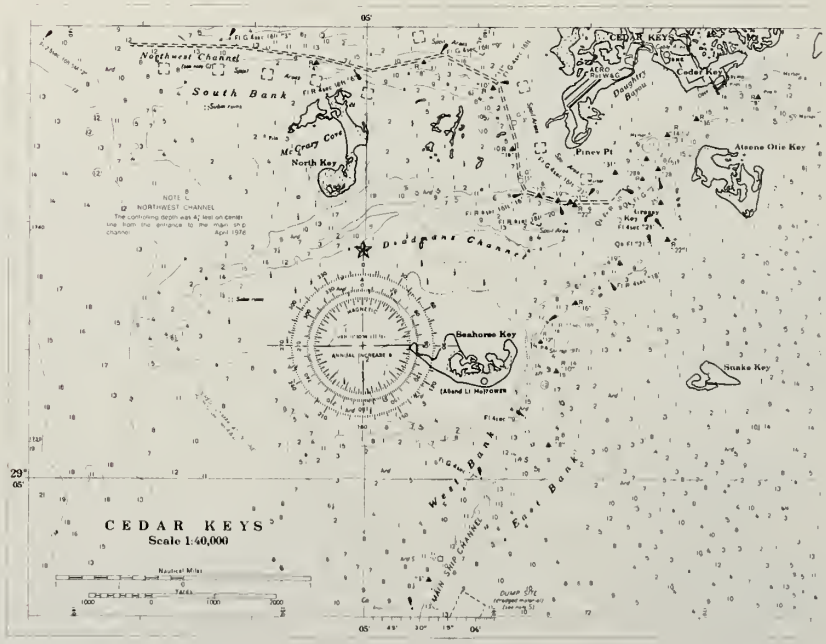

Figure 3a. Cedar Keys Hydrographic Chart (sounding in feet)

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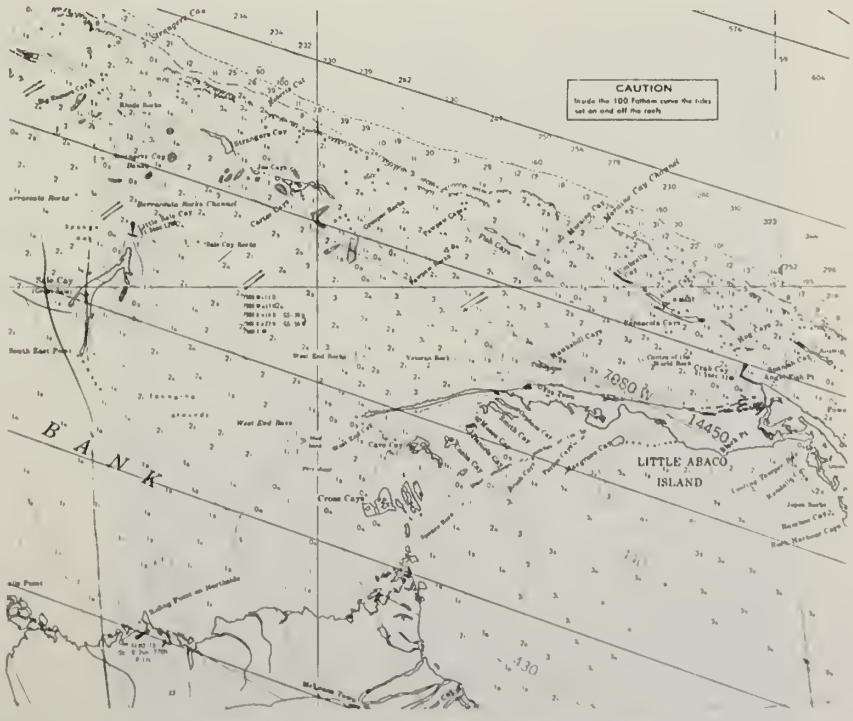

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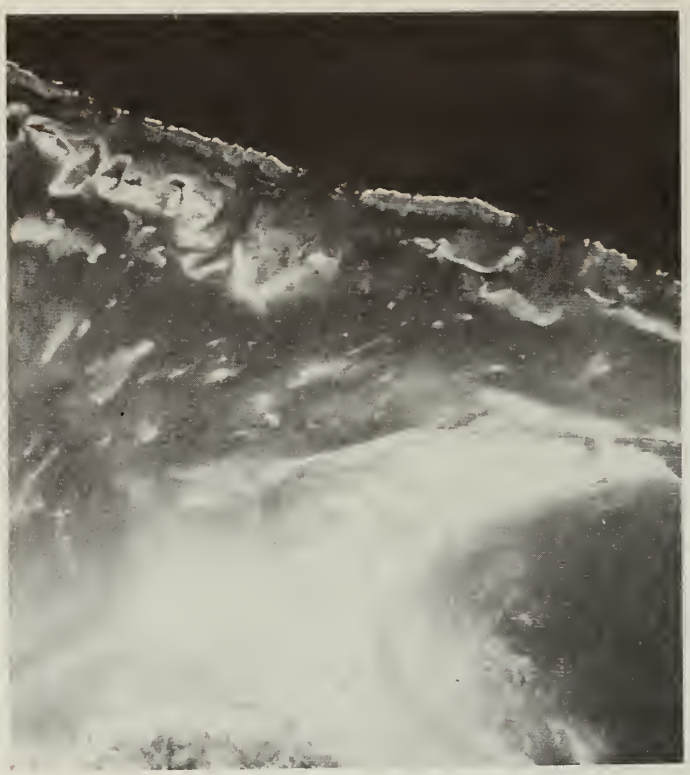
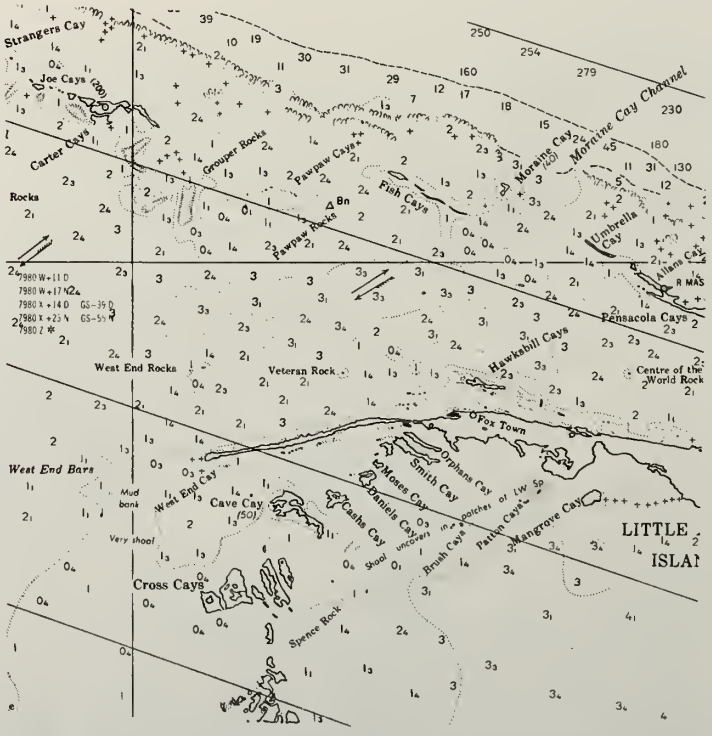


Figure 4b. Little Bahama Bank LANDSAT Color Composite, 26 Mar'77



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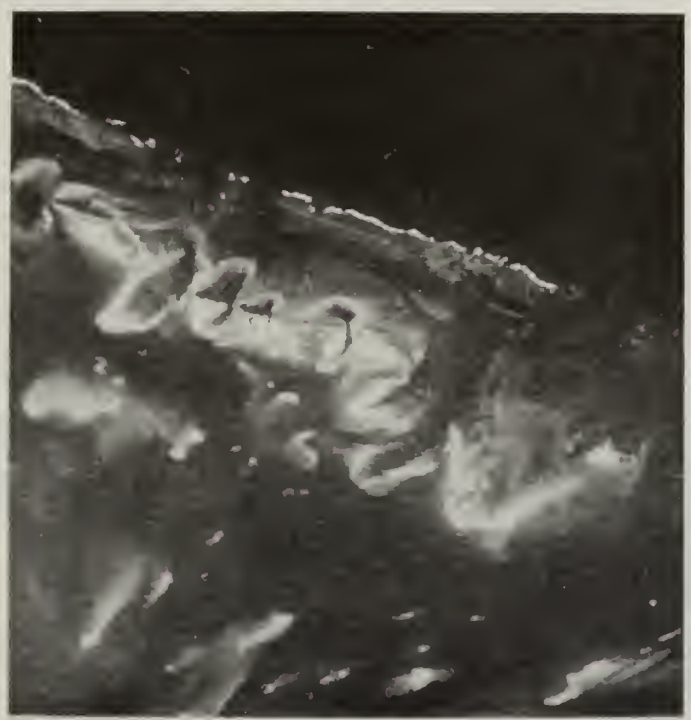

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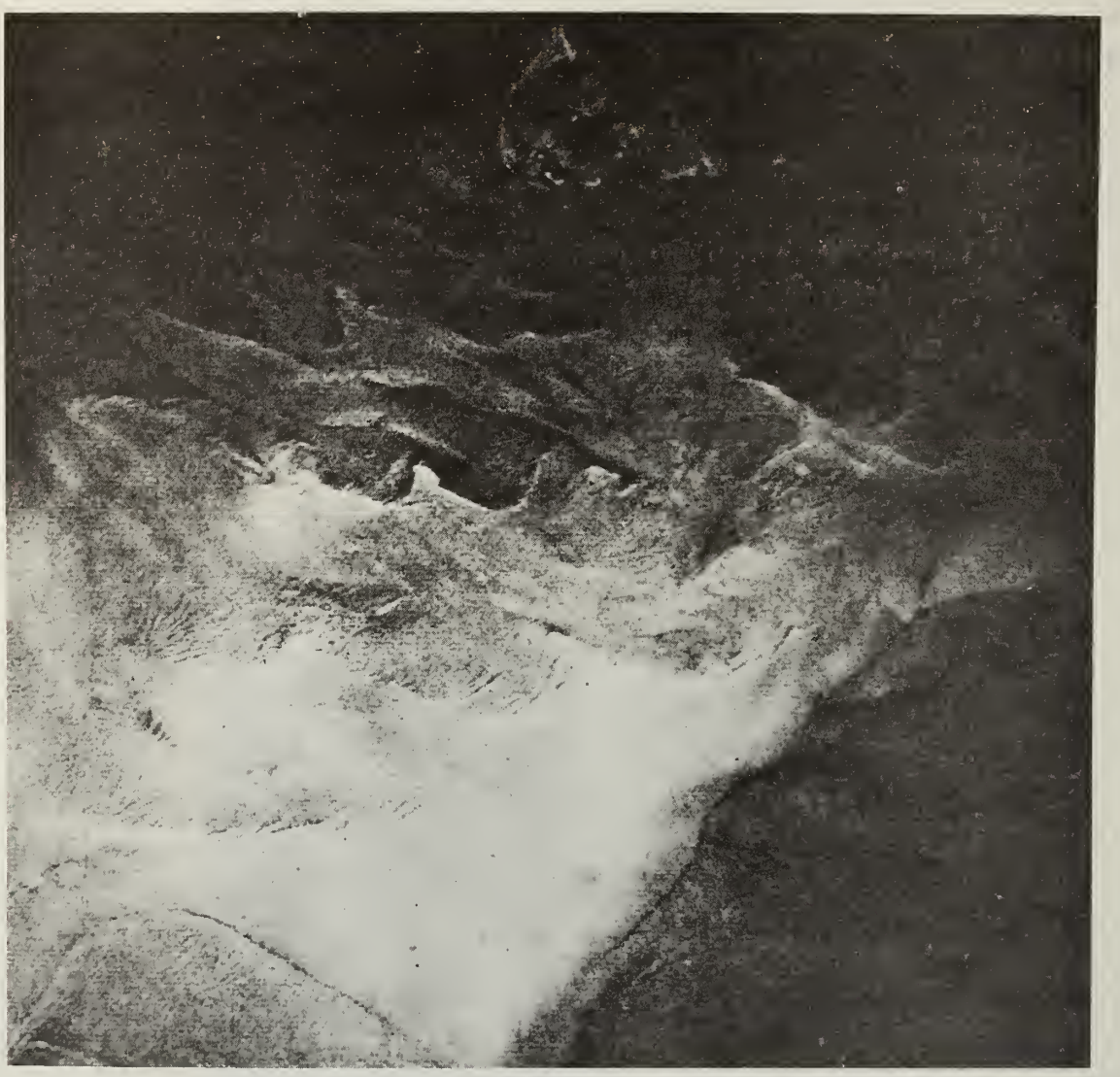

Figure 12. Nantucket Shoals - SAR Image from SEASAT

HYDROGRAPHIC APPLICATIONS OF THE GLOBAL POSITIONING SYSTEM

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ABSTRACT

Global Positioning satellites have been tested under a variety of conditions and have demonstrated exceptional accuracy. The most portable of the Phase I development equipment is the manpack/vehicle user equipment (MVUE or manpack). The purpose of this study was to determine if a manpack is suitably accurate for coastal hydrographic surveying at scales on the order of 1:20,000. The manpack was placed aboard the Naval Postgraduate School Research Vessel (R/V) ACANIA and operated under survey conditions in Monterey Bay, California. This objective required the testing of the manpack developed by Texas Instruments, Inc., under varying survey conditions to determine the degradation of positional accuracy. The limit of the survey scale to which the unprocessed manpack data could be employed in a real-time operation was found to be 1:80,000 and smaller by the positioning error criteria of 0.5mm to the scale of the survey (Umbach, 1976). Applications of differential techniques during the post-processing of the manpack position data increased the limit of the survey scale to 1:40,000 using the same position criteria.

INTRODUCTION

The NAVSTAR Global Positioning System (GPS) is designed to be the most advanced three-dimensional navigation and positioning system in the world in terms of accuracy, coverage, and availabiltiy to all potential users. Testing emphasis of the system has been in the area of high positional and navigation accuracy as applied to military usage. Of importance to military operations is the need for accurate maps and charts. This need has not been addressed by the user community.

This test was conducted to determine the positional accuracy of the Texas Instruments manpack receiver and the scale of survey to which it is applicable. Several criteria exist for determining positional accuracy. The International Hydrographic Bureau (IHB) states that positional error shall seldom exceed 1.5mm at the scale of survey[1]. The National Ocean Survey (NOS) Hydrographic Manual has adopted this criteria with the further stipulation that of the 1.5mm, approximately 0.5mm is reserved for position error. [2]. For our test, we adopted the modification outlined by Admiral R.C. Munson, i.e., "seldom" will be taken to mean less than 10 percent of the time and the 1.5mm value will be interpreted as a 90% accuracy level. [3]. Hydrographic operations will benefit from the implementation of NAVSTAR GPS in several ways: positional accuracy; continuous, worldwide, all weather availability; simplification of survey operations; and cost reduction [4].

HYDROGRAPHIC TEST PROCEDURES

A test plan was drawn up prior to the test itself and covered three major areas. The first was a series of equipment installation tests. These were designed to determine that all the cables and antennas were properly connected, power sources were stable, and the Mini Ranger and the manpack receiver were operating within design specifications.

The second major series of tests were the performance evaluation tests. These involved a static test where the receiver antenna was set up over a known second order control station; a pier test to subject the receiver to low dynamic conditions; and an anchor test designed to subject the receiver to moderately dynamic conditions.

The third major series of tests were survey operation simulations. The manpack was installed aboard the Naval Postgraduate School Research/Vessel (R/V) ACANIA, a 120 foot vessel outfitted for oceanographic work. Since the ACANIA's maximum speed is 9 knots, some adjustments had to be made in the testing to simulate real conditions.

The high dynamic test was run to determine if the satellite signal was lost simulating acceleration normally experienced during inshore surveying. The circle runs were designed to determine if any radial error was introduced in positions. The five-and nine-knot lines were the closest approximation of normal survey procedures.

The testing covered a period of nine days: April 30 - May 8, 1980. Test were conducted at night between 2000 and 0400 local time because that was the period of optimum satellite availability. Weather was good for the entire testing period. Table I gives a breakdown of the data collected by day and by line.

ERROR ANALYSIS

A fairly lengthy error analysis procedure was gone through due to the volume and variety of data collected. Table II gives a breakdown of the error associated with component. It was found that the average error was 7 meters. Table III gives a breakdown of the error associated with the satellite system. [5]. This error averages out to 5 meters for a total error of 12 meters. Taking the best data, computations produced a mean offset of 38±12 meters. If the error total of 12 meters is removed, a corrected value of 26±12 meters is obtained.

CONCLUSION

With updated satellite ephemeris and using stable sets of satellite, results indicate that the MVUE manpack will provide the accuracy required for real-time standard large scale coastal hydrographic operations of 1:80,000 and smaller by the 0.5mm criteria (40 meters).

Post processing of data may bring the accuracies into the 1:60,000 range. Problems associated with the operation of the navigation filters in the receiver need to be resolved, however, before any determination can be made as to further improvement in accuracy.

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Table I - Track Line Data Log

Day	Line	Offset (d)	σ	Azimuth (from South) Mean ϕ°	σ°	Time (GMT)	Number of Events	Bimodal (Low/High)	Line Direction (from North)	Velocity		Number of Satellites
121 (Beach)	L1	23	-	77	-	0605-0607	8	-		dynamic 25 m/sec		4
	L2	36	10	134 (120-140)	10	0811-0844	68	d - high right σ - high right		dynamic 25 m/sec		4
122 (Pier)	L1	102	85	341 (335-350)	4	0710-0725	57	d - high left σ - high right		-		2
	L2	87	12	53 (9-80)	11	0848-0912	83	d - high left σ - high right		-		2
123 (Anchor)	L1	150	95	302 (290-310)	6	0738-0814	113	-		-		4
124 (High Dynamic)	L1	310	20	29.3	7	0600-0647	171	σ - high left	345°	(M/S) 4.5	(Knots) 8.7	3/2
	L2	1003	150	100	5	0727-0911	166	-	075°	4.5	8.7	2
125 (Circle and Lines)	L1	31	13	100	14	0540-0620	129	-	circle left	4.5	8.7	3
	L2	30	27	292	21	0638-0718	122	-	circle right	4.5	8.7	4
	L3	297	266	132 (90-120)	19	0755-0820	74	d - high left/ low right	000°	4.5	8.7	4/5
	L4	268	166	112 (70-140)	24	0826-0839	51	d - high left	180°	4.3	8.4	5/4
	L5	21088	4674	267 (254-270)	3	0901-0920	54	d - high right	270°	4.4	8.6	4
	L6	-	-	-					090°	4.3	8.4	4
126 (Nine Knot Lines)	L1	102	5	197 (190-210)	4	0558-0615	62	-	270°	4.0	7.8	3
	L2	116	7	188 (180-195)	5	0622-0637	33	-	090°	4.0	8.6	3
	L3	363	100	121 (115-130)	4	0652-0708	62	d - high left	270°	3.7	7.2	4
	L4	54	41	125 (100-150)	11	0744-0800	60	-	180°	4.0	7.8	4
	L5	20	7	152 (120-190)	21	0809-0824	58	σ - high right	000°	3.7	7.2	4
	L6	33	10	240 (210-280)	13	0844-0902	70	d - high left	135°	3.9	7.6	3
	L7	42	10	262 (250-280)	6	0617-0936	59		045°	3.5	6.8	3
	L8	55	13	282 (275-300)	7	0950-1007	63	σ - high right	270°	2.7	5.2	3
127 (Five Knot Lines)	L1	671	133	152 (140-170)	8	0646-0700	36	- high left	300°	3.5	6.5	3/2
	L2	187	176	119 (115-125)	2	0721-0729	33	-	120°	3.7	7.2	4
	L3	50	10	133 (125-140)	5	0737-0750	44	-	300°	3.8	7.4	4
	L4	32	13	157 (140-200)	13	0800-0815	53	-	210°	3.9	7.6	4
	L5	33	22	158 (145-210)	17	0822-0833	40	-	30°	3.7	7.2	4
	L6	33	11	218 (200-225)	12	0858-0915	61	-	210°	3.8	7.4	3
128 (Beach)	L1	49	65	317 (0-360)	25	0631-0705	70	-	-	static 0		4
	L2	7	3	313 (0-360)	29	0735-0805	49	d - high left σ - high left	-	static 0		4

A.	Geodetic Control	.4m
B.	Position Error[1] (due to coordinate shift)	4m
C.	Inverse[2] (Ellipsoid vs. Plane Computation)	.02m
D.	GDOP	4m
E.	Range Correction	3m
F.	Meteorological	.06m
G.	Station Elevation	.1m
H.	Timing[3]	0 - 4 m
I.	MRS III Positioning	.5m
J.	Antenna Motion	0 - 2 m

1 - Based on offset between Doppler station and abridged Molodensky Formulas
2 - Maximum at distances less than 1000 meters
3 - Depends on trends in data

TOTAL ERROR

$$E_{T_{min}} = e_A + e_B + e_C + e_D + e_E + e_F + e_G + e_H + e_I + e_J$$

$$= .4^2 + 4^2 + .02^2 + 4^2 + 3^2 + .06^2 + .1^2 + 0 + .5^2 + 0$$

with e_H (timing) = 0 and e_J (antenna motion) = 0

= 6.4m

$$E_{T_{max}} = .4^2 + 4^2 + .02^2 + 4^2 + 3^2 + .06^2 + .1^2 + 4^2 + .5^2 + 2^2$$

with e_H = 4m and e_J = 2m

= 7.8m

$E_{T_{avg}}$ = 7m

RAW DATA: 38 meters with 11 meter standard deviation

CORRECTED: 38 - 7 = 31 meters

Table II - Error Analysis Associated with Test Area and Equipment

Uncorrected Error Source	User Equivalent Range Error, 1	
	Meters	Feet
SV Clock Errors Ephemeris Errors	1.5	5.0
Atmospheric Delays	2.4-5.2	8.0-17.0
Group Delay (SV Equipment)	1.0	3.3
Multipath	1.2-2.7	4.0-9.0
Receiver Noise and Resolution Vehicle Dynamics	1.5	5.0
RSS	3.6-6.3	11.8-20.7

[Millikin, et.al., 1978]

Table III - Error Analysis Associated with Satellite System

MS. DUNN: Do we have any questions?

CDR JOHN E. CHUBB, Mapping, Charting and Geodesy Programs DMA: I notice that you had the antenna way up on the mast and the green box down in the dry lab.

Does Texas Instruments say that the long wire from the antenna down have any effect?

MS. DUNN: They told us they would prefer we only use an antenna length of 5 meters, I believe.

MR. REES: 3 meters. We upped it to five.

MS. DUNN: We originally tried it with 15, and the set just went belly-up on us. It wouldn't give us anything at all.

MR. REES: That's the first couple of nights that you saw, where we lost all satellites. That was the reason we were losing the signal strength.

MS. DUNN: We completely reconfigured the thing and moved the satellite receiver up to the bridge, and after that we got weak signal indications, but not as often, and it was not as poor.

CDR CHUBB: The speed of propagation through the air or through the wire you have to take into account. You are not measuring necessarily where the antenna is, if it's got a pre-determined distance between the antenna and the receiver.

MS. DUNN: Yes. We are aware of the fact that we may have introduced a problem there, but there was simply no other way to do it, unless we were going to have somebody stand up on the top of the ship.

CDR CHUBB: A related question. You made inference to the antenna mast motion. Did you have any kind of conclusion regarding whether or not the mast swinging on the rolling ship was going to affect the data.

MS. DUNN: The only time it really appeared to show up was when we did the high dynamic turn, and unfortunately we have no good data to compare it to, so we have no way of really knowing how badly those positions were deteriorated by the swing of the mast, in the midst of the fast turn like that.

MR. REES: We also had an additional problem. The data rate that we could take from the satellite receiver was only every 15 seconds manually, because we didn't have any recording interface. There is one in existence, but it was not made available to us.

The next test, the differential test, NOAA is having some recording made.

CDR CHUBB: One last question. You refer to degraded accuracy long after the satellite update. Could you explain a little bit more about that? In an operational environment, how often are they going to update -- if the satellite update moves it from 5 meters to 600 meters, then that is something that you have to --

MS. DUNN: They are planning to update the satellites once every 12 hours, once it goes into operation.

Now, the problem with the system as it exists right now is, I think they have seven satellites up. We only had 5 available to us, one of which was bad, had a bad cesium on board.

The update, they only do once every 24 hours now, because nobody of any consequence, we were told, was doing any testing. So we had to take what we could get. They updated at midnight our time, so we had satellite availability from 10 o'clock at night until four in the morning. So two hours of the data that we got was bad.

They update anywhere from one to four times, depending on the satellite. Because they had one satellite that sort of acts as a control for the other four. It checks the ephemeris data. And for those satellites, they just don't have that much ephemeris data. They haven't tracked them enough to know where they are going to be over a 24-hour period. So they update them. Within 30 minutes of the update, you have supposedly what they call a URE, user range error, of 5 meters. By the end of that time, it can be anywhere up to a hundred, and when you plug all four satellites in, it is a geometric problem after that. It just gets increasingly worse as the day goes on.

Hopefully, as they track the satellites, and apparently, from what I just read recently from the IEEE conference in Atlantic City, they are going to try to use the ephemeris data from a transit system to more accurately plot where the GPS satellites are going to be. How far they are going to get with that, I don't know. They seem to think they will have better ephemeris information and reduce this error problem.

ADAM KERR, Canadian Hydrographic Service: A few questions. The manpack, does it use two frequencies?

MS. DUNN: Yes, it does.

MR. KERR: There are two codes you have with the system. I presume that relates to the ephemeris, does it, there?

MS. DUNN: There are two codes. The precision code and the course acquisition code.

The entire data word that is transmitted from the satellite on both codes, I believe, contains ephemeris data. The precision code gives you a little more information and more precisely locates you. But all of the ephemeris data, the Almanac data, the time standards, the health of the satellite, all of the stuff is contained within the data message that comes down from the satellite.

MR. KERR: Were you able to use the precision code on this observation?

MS. DUNN: Yes.

MR. KERR: And how many hours of good operation were you having with the five or the four satellites that you were actually using at this particular time?

MS. DUNN: Well, I have to be honest with you. We only got the set two days before we actually started conducting the test. So the first five days of our testing was as much learning to use the equipment as it was getting usable data out of it. I would say that the last four days that we had it was really the best, because then we knew what to do with the system. We had the satellite receiver in the right place, we had the recording drill down, and we were showing very good data. So I would say about 16 hours over the last five days.

MR. REES: That is in 3-hour intervals, which was limited by the orbits in the satellite.

MR. KERR: Right. And you said that you have a degradation over a period of time. You discussed that just now.

Can you get that data and post process your information? Could you get all this information and post process it? Is it possible to get the ephemeris data afterwards?

MS. DUNN: The people at Vandenburg told us that it would be possible. They would generate this data for us, and make it available to us, and it would be possible for us to go back and compute the geodetic -- the geometric dilution of precision on the satellites, and to take the corrected ephemeris data, and to go back and plug all of this in and come up with a better estimate of our position. The problem is that John and I were thesis students, and we were trying to beat a time limit, so we really didn't have the time to do the kind of job on processing the data that we would have liked to.

I am in the process now of getting the data back, which is still out in Monterey, and that is something I would like to do in my own time if I could.

MR. KERR: Thank you.

LCDR LEWIS LAPINE, Chief, NGS Operations Division: I would like to know how you related WGS to NAD?

MS. DUNN: Very poorly.

LCDR LAPINE: You don't know, then, that maybe some of this 26-meter error is due to the relationship of the data?

MS. DUNN: What we did we got our hot little hands on the Molindinski formulas, and we actually -- we had to use the abridged formulas.

We did not know what our elevation was above the geoid at that point, so we used the abridged formula to compute the latitude and longitude, or convert the latitude and longitude from NAD 27 to WGS 72, and then do the UTM transformation from that. We know that there was error introduced in that problem.

We were unable to get the necessary information that we needed -- we didn't have the time, really, to determine how large that error was. We know there is one there.

LCDR LAPINE: Was the doppler receiver on any of the Mini-Ranger stations?

MR. REES: No.

We found the Doppler stations after we conducted the test.

We used those to test the formulas that we were using, because they had been calculated using the full Molindinski. So we just compared that one with the abridged version.

MS. DUNN: We also found out in Niagara Falls, since these doppler stations that we were using were done in 1973, that the positions that we were using had probably been corrected since then, and we did not have the updated information. So each increasing iteration of this is adding an error factor in there that we are unable to evaluate at this point.

MR. REES: We used the GPS in static mode, and used the statistical data that we used, just as an example, the offset with the doppler station, we had a 9-meter offset in a given direction. With the GPS data, we had a 7-meter off-set in the same direction. So, I feel myself it was pretty legitimate.

MS. DUNN: Reasonably accurate.

MR. LAPINE: What about this 26-meter offset?

Was that pretty much a constant 26 meters, with the exception of that one line where you had the 600-meter difference?

MS. DUNN: Consistently, when we knew the data was good, when everything was working well, we consistently came up with this 35 plus or minus 10 to 12 meters, and if we can account for 12 meters of that, 7 meters in the Mini-Ranger system, and five in the satellite system -- you know, these are averages, of course -- it is going to go either way, that is the way that goes. But we consistently came up with the same set of figures, and we just have the feeling that if you can't bring that 26 meters down, and everybody is buzzing around about there being this 25-meter per second velocity factor that nobody is willing to explain or talk about, we had much rather shove it off on them than take responsibility for it ourselves.

MR. REES: We didn't fudge the error analysis. We both sat down and thought of everything we could for error, geodetic positioning, range error, meteorological, and just totaled them up, and what number fell out, we subtracted out, and there was that number, and coincidence or what, that was our question.

MS. DUNN: The other interesting thing was that there seemed to be a preferred offset. That was the other thing that always bothered us. You would assume that if it were a random thing, that your offset would be around the clock, and there was always -- the bias was always towards the satellites, for instance, and you just kind of wondered if there is something there that you are not --

MR. REES: Somewhere in the filters or something.

LCDR LAPINE: Thank you.

MS. DUNN: Thank you.

MR. REES: I guess the basic purpose was to see what scale survey you could use this thing at. And we found by all of our error analysis, I guess one to 60,000 is pretty legitimate. Differentially, one to 40,000, and if you had two sets working simultaneously in a differential mode, my speculation would be 10 meters, because we always had the --

MS. DUNN: Don't speculate. Tim is going to give us a report on that.

MR. REES: Plus or minus 10 meters, or 11 meters. We always had that in there. So it should be a good system.

MS. DUNN: Anymore questions?

LCDR ETHRIDGE: The application that you have addressed here is using the differential unit aboard ship, which as we all know is the dynamic, and certainly less than the optimum place to use it.

What I'm wondering, if you put the GPS receiver on a shore station and let it set there for a certain amount of time, what kind of accuracy would you get with this operation, and I'm thinking specifically of those people who still have to work with traditional ground methods in putting in shore stations along the beach for mini-rangers.

MS. DUNN: I just recently read a paper that was given at the IEEE conference in Atlantic City back in December, where some people at Dahlgren were running this, because they are interested in using GPS for geodetic positioning, just as you would use the Doppler tracking, and they are making a rather blanket statement that, after 5 days of continuous tracking, they can give you a position accuracy of 30 to 65 centimeters.

Thank you.

LCDR ETHRIDGE: Thank you very much, Penny and John, for your good presentation.

TEST RESULTS OF A DIFFERENTIAL GPS RECEIVER

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ABSTRACT. In January of 1980, the Global Positioning System (GPS) Joint Program Office conducted a number of tests of a differential GPS receiver at the Yuma Proving Ground. Using an extremely accurate system of laser trackers as a reference, they demonstrated that the differential GPS receiver achieved an accuracy of better than 5 meters (1σ). The results of several of these tests are presented.

The results of these tests are significant in that they demonstrate the potential of GPS for hydrographic surveying at survey scales as large as 1:5000. Standard GPS accuracy (approximately 10 meters, 1σ) would limit hydrographic surveying to survey scales of 1:20,000 or smaller. A differential GPS receiver could also be used for other applications such as airborne laser hydrography, or photogrammetry without the need to establish photo survey control.

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HYDROGRAPHIC SURVEY REQUIREMENTS

The two fundamental characteristics associated with any positioning system suitable for hydrographic surveying are horizontal accuracy and maximum operating range. The accuracy requirement for horizontal positioning systems recommended by the International Hydrographic Bureau[1] is as follows:

> "The indicated repeatability of a fix (accuracy of location referred to shore control) in the operating area, whether observed by visual or electronic methods, combined with plotting error, shall seldom exceed 1.5 mm (0.05 in) at the scale of the survey."

The term "seldom" is undefined but has been interpreted in the past[2,3] to mean "less than 10 percent of the time." Given this interpretation, the 1.5 mm figure represents a 1.645σ value. One can then easily convert these quantities into the more standard 1σ accuracy specification. For typical hydrographic survey scales, these accuracy requirements are listed in Table 1.

Table 1: Hydrographic Accuracy Requirements

Survey Scale	Accuracy 1.645σ (90%)	Accuracy 1σ (68%)
1:5,000	7.5 m	4.56 m
1:10,000	15 m	9.1 m
1:20,000	30 m	18.2 m
1:40,000	60 m	36.5 m
1:80,000	120 m	73.0 m

The National Ocean Survey (NOS) presently maintains a broad inventory of electronic positioning systems such as microwave systems (Del Norte, Miniranger, etc.), medium frequency systems (Argo, Raydist, etc.), and Loran C to achieve the best available accuracy at increasing distances from shore. Accuracies obtainable with currently available state-of-the-art systems, however, limit the maximum offshore range at which larger scale hydrographic surveys may be performed.

Quite naturally, difficulties are encountered in maintaining such a broad inventory of equipment. Large amounts of manpower are also required to set up and maintain the electronic shore control stations. Under certain circumstances, large scale, inshore surveys are performed using such labor intensive methods as horizontal sextant angles or range-azimuth techniques.[4] Both of these methods require a great deal of time and manpower to establish the required visual and electronic shore control stations, to perform the survey, and to process the manually gathered data.

APPLICABILITY OF GPS TO HYDROGRPAHIC SURVEYING

Hydrographers who are aware of the upcoming Global Positioning System (GPS) being developed by the Department of Defense often look upon it as the ideal positioning system. With GPS, hydrographers will for the first time be able to utilize a single positioning system to perform worldwide, automated surveys without the need to establish shore control stations.

Upon closer examination, however, this is seen to be not quite the case. Under the planned constellation of 18 satellites, the horizontal positioning accuracy of the best "P code"* GPS receivers will be on the order of 10 m (1σ). This level of accurcy will be insufficient in performing 1:5,000 or 1:10,000 scale hydrographic surveys. As these inshore surveys are the most time consuming and labor intensive, this represents a serious disadvantage. Fortunately, methods exist to improve upon this level of accuracy; several of these could be appropriate for hydrographic surveying.

SHIPBOARD TEST RESULTS

Table 2 shows the results[6] obtained during tests of two prototype GPS receivers manufactured by the Magnavox Advanced Products Division and tested by the GPS Joint Program Office as part of the Phase I developmental testing program. Both sets are similar with the exception that the single channel Y-Set receives its signals from each satellite sequentially while the 4 channel X-Set is designed to operate in more dynamic environments and receives its signals from four satellites simultaneously.

The test vehicle during this series of tests was Navy Landing Craft LCU-1618. The reference sytem employed consisted of a Motorola Miniranger System using four remote transponders based on San Clemente Island. Previous testing of the Mototrola reference system had shown that horizontal positioning accuracies on the order of 2 m could be expected using the 4 transponder installation.

During this series of tests only three satellites were available giving an operational window of only three hours per day. Normally four satellites are required for GPS operation. Surface vessels, however, may operate using only three satellites as the users altitude is known. This limited number of satellites did result in high values of Horizontal Dilution of Precision (HDOP) during portions of the test periods which degraded the test results. Under the full constellation of 18 satellites the horizontal positioning accuracy will improve.

The horizontal position and velocity accuracies obtained during these shipboard tests are representative of all GPS testing aboard a wide variety of platforms including trucks, helicoptors, aircraft, etc.[7] It can also be seen that Y-Set performance was comparable to the higher performance X-Set. It would therefore be logical to assume that shipboard operation did not significantly affect GPS receiver performance.

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* Those unfamiliar with GPS terminology or theory should obtain a copy of Ref No 5 which serves as an excellent introduction to GPS.

Table 2: Shipboard Test Results

USER EQUIPMENT	DATE	AVERAGE HORIZONTAL POSITION ERROR (METERS)	AVERAGE HORIZONTAL VELOCITY ERROR (METERS/SECOND
X-SET	6 DEC 78	7.7	0.28
	7 DEC 78	24.9	0.34
	8 DEC 78	9.1	0.30
	11 DEC 78	23.6	0.40
	12 DEC 78	8.6	0.25
	13 DEC 78	9.4	0.30
Y-SET	11 DEC 78	11.9	1.10
	12 DEC 78	19.6	0.63
	13 DEC 78	13.1	0.77
AVERAGE		14.2	0.49

ENHANCEMENT TECHNIQUES

Listed below is a summary of the various error sources which degrade accuracy of GPS receiver.[5]

ORIGIN	ERROR	CHARACTERIZATION
Ground Segment and Satellite Equipment	Satellite Ephemeris	Bias
	Satellite Group and Clock	Bias
User Equipment	Psuedorange Noise	White noise
	Range Quantization	White noise
	Range Mechanization	White noise
Environmental Effects	Ionospheric	Markov
	Tropospheric	Bias
	Multipath	White noise

To compute the uncertainty in horizontal position these errors are combi on a root-sum-square (RSS) basis and the resulting "pseudorange" error multipl by the HDOP. The HDOP will vary as a function of the relative positions of orbiting satellites with respect to the user.

Various methods exist to enhance the accuracy normally obtainable using the GPS satellite network for mobile users, these include:

1 Receiver hardware/software improvements,
2 Integration with external sensors (inertial measurement unit, velocity sensors, etc.),
3 Post Processing (smoothing) of data,
4 Operating only during selected periods, and
5 Differential Positioning.

While techniques 1, 2, and 3 each offer several advantages only minimal improvement is possible. These techniques may reduce random errors but they cannot remove large, long term biases such as: satellite ephemeris errors, satellite clock errors, and ionospheric effects. By operating only during periods of improved HDOP, (technique 4), the horizontal accuracy attained during the survey will improve. The disadvantage of this technique, however, is that the length of these operating windows may prove unacceptable depending upon the particular application.

DIFFERENTIAL POSITIONING

Differential positioning is a technique whereby a second, similar positioning system is located at a known surveyed location near the survey site. In its simplest implementation this receiver computes error messages in terms of latitude and longitude which are then applied to the user's receiver as correction factors either in real time or during post-processing. In this manner, bias errors which are common to each of the two receivers are reduced in magnitude. The distance between the two receivers over which these corrections apply is a function of the environmental factors involved and the relative geometry between the two receivers and the stations or satellites from which the signals are transmitted. The differential technique has been employed in the past with such navigation systems as Loran C[8], Omega[9], and Transit[10] resulting in substantially improved navigation accuracy.

While interest in differential GPS for mobile applications has been minimal, its applicability to geodesy has been studied extensively.[11] The results of these studies indicate that after only a few hours of observation relative positioning accuracies on the order of several centimeters will be possible for stations placed 100's of kilometers apart. While the geodetic technique uses certain methods such as the measurement of the accumulated Doppler count and data averaging which would be inappropriate for a mobile platform, both methods attempt to remove the same error sources.

TEST OF THE DIFFERENTIAL GPS CONCEPT

In January of 1980, the GPS Joint Program Office conducted a number of tests of a differential GPS receiver[12] at the Yuma Proving Ground as a follow-on to the Phase I developmental testing program. The purpose of these tests was to examine the potential of differential GPS to perform such missions as terrain following and precision landing approaches for which standard GPS accuracy would prove unacceptable. The test vehicle during each of these tests was an Army UH-1 helicopter.

The differential test at Yuma used existing hardware whenever possible and incorporated necessary software changes when required. The ground-truth receiver consisted of a modified Magnovox X-Set GPS receiver located at a known surveyed location which generated a three-dimensional error message every 30 seconds. The normal function of this receiver is to monitor the performance of the GPS satellite network over the Yuma test site. The error message was transmitted via a microwave data link to a modified Texas Instrument HDUE (High Dynamics User Equipment) GPS receiver which applied the correction in real time. The microwave data link employed was a satellite ground transmitter which had been used during previous tests to support testing when satellites were unavailable. The signal from this ground transmitter was received by a fifth channel of the HDUE which would normally have been used for the dual frequency ionospheric correction measurements. During this series of tests the dual frequency ionospheric measurement feature was inhibited in each of the two receivers allowing the ionospheric error to be removed differentially. Operation in the differential or non-differential mode was designed to be selectable by the operator (see figure 1).

The reference system used during each of these tests was a set of laser trackers whose horizontal accuracy is stated to be on the order of 1.5 m (1σ). To further demonstrate the potential of differential GPS, the normal accuracy of the GPS network was purposely degraded by failing to upload the satellite ephemeris and clock messages to each of the satellites at the normal interval.

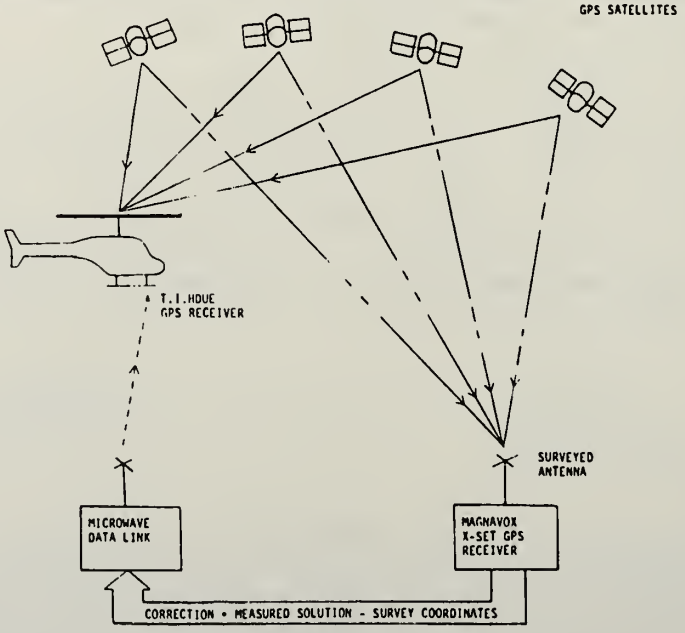

Figure 1: Differential Test Implementation

YUMA TEST RESULTS

Figure 2 illustrates a segment of the data obtained during the 11 January 1980 test which is representative of the results obtained in the diferential mode.* Prior to operating in the differential mode, the horizontal positioning errors are seen to be on the order of 20 m. Upon entering into the differential mode these errors were reduced to better than 5 m.

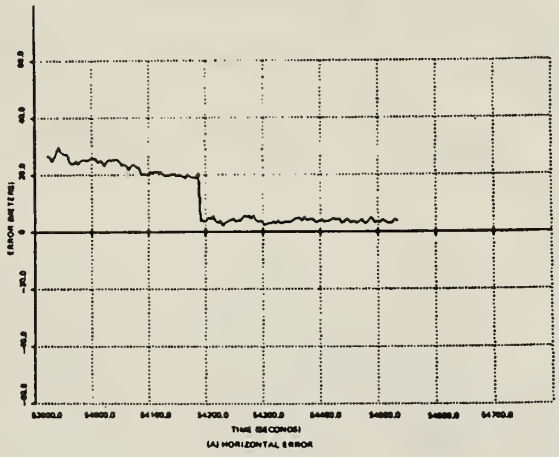

Figure 2: Horizontal Error

While of no benefit to hydrographers, substantial improvements in vertical accuracy performance was also obtained during these same tests. Figure 3 indicates the vertical errors obtained during the same period in both the non-differential and differential modes.

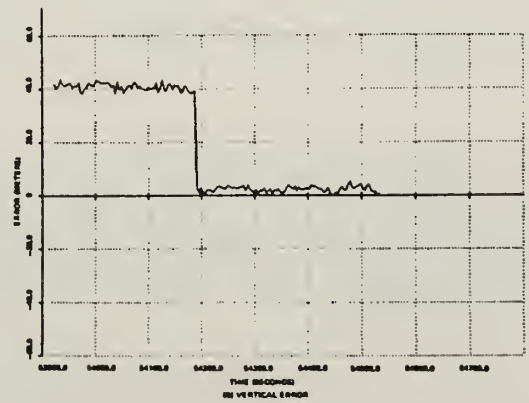

Figure 3: Vertical Error

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* All data courtesy Texas Instruments Inc.

Table 3 is a tabulation of represenative results obtained during 4 different differential tests aboard the UH-1 helicoptor during the month of January, 1980.

Table 3: Differential Receiver Performance

Error (meters)

Date		Mean	RMS	Std Dev	CEP	PE
09 Jan 1980	Horiz	4.2	4.7	2.1	3.8	
	Vert	-5.2	5.5	1.9		5.2
10 Jan 1980	Horiz	5.0	5.3	1.8	5.0	
	Vert	3.9	4.5	2.2		4.0
11 Jan 1980	Horiz	3.8	3.8	0.8	3.7	
	Vert	1.4	2.0	1.5		1.5
16 Jan 1980	Horiz	3.6	3.8	1.5	3.4	
	Vert	2.1	2.6	1.5		2.1

Due to the manner in which the differential corrections were implemented during this series of tests no improvement in velocity accuracy was obtained by using the differential mode. Normal GPS velocity accuracy could be sufficient however for certain applications. If corrected differentially, the velocity accuracy obtainable could possibly exceed that of bottom tracking Doppler sonar systems (approximately 0.1 knot).

Following the January tests it was discovered that a poor connection in the antenna assembly may have degraded the performance of the HDUE receiver. During subsequent data analysis it was further determined that an uncompensated lever arm of 3.29 m existed between the laser retroflector and the HDUE antenna. These problems have since been corrected, and in future tests it is anticipated that the observed performance will improve.

ADDITIONAL APPLICATIONS

Beyond routine hydrographic surveying or navigation, GPS receivers could be used in a wide variety of oceanographic applications which require precise knowledge of vessel position or velocity. Such applications include:

Geophysical Surveys,

Pollution Monitoring,

Underway Measurement of Currents, and

Biological Resource Assessment.

Depending on user requirements, operation in the differential mode may be required in order to obtain the desired accuracy.

When integrated with an inertial measurement unit, the position and orientation of an aerial camera may be determined at the time the photograph is taken. In this manner a wide variety of photogrammetric missions may be performed without the need to establish photo survey control. Applications for such photogrammetric missions could include:

Shoreline Mapping,

Photobathmetry,

Surface Circulatory Current Surveys, and

Pollution Monitoring.

The potential of using such an integrated GPS/inertial system to support 1:50,000 scale photomapping operations has been demonstrated previously.[15] In the differential mode substantially improved performance may be expected.

An integrated GPS/inertial system could also be used to support new and more efficient airborne survey techniques. Such techniques include:

Airborne Laser Hydrography[14],

Shoreline Mapping[15] (Using Multispectral Scanner Techniques), and

Pollution Monitoring (Using Multispectral Scanner or Laser Techniques).

Presently the GPS program is in Full Scale Engineering Development (Phase I and a variety of operational GPS receivers are being developed both under D contract and commercially. Testing of the receivers is scheduled to begin in t Fall of 1982. Currently, however, no plans exist to operate any of the receivers in the differential mode or to determine what differential accura will be achievable under the full constellation of 18 satellites aboard a ship small launch. It is recommended that NOS undertake a study to determine t feasibility of modifying these receivers for differential operation and quantify what benefits (cost savings, increased productivity, manpower saving etc.) would accrue from operating such receivers.

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DISCUSSION

LCDR ETHRIDGE: Are there any questions?

JOHN V. WATT, Canadian Hydrographic Service: One question on the range that you were operating from your fixed station, and another question; how far do you think you could operate from it and not degrade what you were seeing as improved results?

LT(JG) RULON: In this test, the helicopter was only some 8 miles away from the ground-based receiver. As far as the distance that it could be operated, certain errors will be eliminated independent of range. Others will degrade as a function of the range between the two receivers. Due to the relatively high orbit of these satellites, it looks like that you could use the differential correction for several hundreds of miles.

LCDR ETHRIDGE: Thank you, Tim.

I would like to add a couple of comments. This global positioning system really sounds good to me. Of course, we have a long way to go in developing this system and making it operational. One of the other attractions of the system is that it is kind of independent of the weather. When it's foggy, it still works adequately. You don't have to lay at anchor and wait for the weather to clear, and when the rain storms come in, it still works adequately. You don't have to lay to and pay overtime for services you are not receiving.

So, that is another factor we should all keep in mind, and I hope that the research and the development along these lines continues, and I personally am looking forward to the day when these satellite aided techniques are a reality, and we can move into a phase of space hydrography.

With that I would like to wrap up this final session for the hydro conference today. I certainly want to thank all the speakers for my session, and I want to thank all of you for participating.

USE OF NATIONAL OCEAN SURVEY HYDROGRAPHIC SURVEY DATA

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ABSTRACT. The National Ocean Survey (NOS) has traditionally conducted hydrographic surveys for the purpose of acquiring data for charting coastal waters for the mariner. An increasing awareness and interest in environmental concerns has generated a greater demand for bathymetric maps. It is important to note that bathymetric maps produced from hydrographic survey smooth sheets normally will result in inaccurate bathymetric maps. However, bathymetric maps can be produced from the unrounded digital sounding data acquired during a hydrographic survey. The differences between a hydrographic survey smooth sheet and a bathymetric map are discussed.

INTRODUCTION AND DEFINITIONS

The NOS started collecting hydrographic survey data in 1835 for the purpose of charting coastal waters in the New York area. Since that time nearly 10,000 hydrographic surveys have been conducted. What kind of surveys were these? What use has been made of the survey data? What use could be made of the archived survey data? To answer these questions, this paper identifies some potential uses and misuses of hydrographic survey data.

Definitions of terms as used in this paper follow.

Bathymetry -- The art or science of determining ocean depths. The water depth measurement process.

Bathymetric map -- A topographic map of the seafloor. Bathymetric maps are designed especially for geophysical studies.

Hydrography -- The determination of the depth of water and the configuration of the bottom for purposes of nautical chart construction.

Hydrographic survey smooth sheet -- The final survey drawing or map portraying the findings of a hydrographic survey.

Nautical chart -- A map designed for purposes of navigating the ocean or other body of water, depicting shorelines, topography of the bottom, and aids and dangers to navigation.

Sounding -- Measurement of the depth of water.

Reduced sounding -- A sounding corrected for vessel draft, tide, sound velocity in water, etc.

Rounded sounding -- A sounding whose decimal part has been deleted and whole units part modified according to an established procedure.

DATA COLLECTION

How are NOS hydrographic survey data acquired?

Sounding data normally are collected according to some predetermined sounding line scheme. The primary scheme of sounding lines usually is a series of parallel lines at a constant spacing. Crosslines usually are perpendicular to the primary sounding line scheme. "Splits," additional sounding lines, may be run to help better delineate bottom features.

During hydrographic surveying, the hydrographer is required to develop shoals, natural and dredged channels, and other features critical to ship movements. Depressions, canyons, holes, and any type of "deeps" which are at depths greater than what is relevant to surface navigation are not normally developed to the full extent in present day hydrographic surveys.

The present standard NOS echo sounder used with normal sounding line spacing does not give 100 percent bottom coverage. However, present day bottom coverage is more complete than in the early years of the Coast Survey when lead lines and sounding poles were the standard. Hydrographic surveys do not necessarily require 100 percent bottom coverage as tendencies of bottom slope provide clues to the hydrographer of potentially dangerous shoals which will require more extensive surveying. However, a clue of a potential danger to navigation may not be provided by sounding lines in the vicinity of a wreck, a pinnacle rock, or an obstruction of small extent.

How much of the bottom is presently being covered by a survey echo sounder? On a 1:10,000-scale survey, with normal line spacing of 100 meters, in water depths of 75 feet, about 3 percent of the bottom is portrayed on the echogram.

This percentage of bottom coverage, resulting from the primary sounding line scheme, seems to have proven satisfactory for the ultimate purpose of the hydrographic survey--nautical charting. By evaluating adjacent sounding lines, tendencies for shoals can usually be seen and "splits" may then be run to provide a development of the shoal. Developments normally are not conducted about "deeps" with the same frequency as developments about

shoals. Hence, the bottom topography which would be shown on a well-developed truly bathymetric survey is absent on the hydrographic survey.

DATA PROCESSING

In transforming sounding data into a hydrographic survey smooth sheet, the Marine Centers apply appropriate correctors to the raw soundings to obtain the reduced soundings. The reduced soundings are then rounded off, usually to a whole number, so that they can be plotted on the hydrographic survey smooth sheet.

How is a sounding rounded? In contrast to the basic mathematical round-off method in which decimal values of .5 and greater are rounded up, and values less than .5 are rounded down, the standard NOS sounding round-off method is for decimal values of .8 and greater to be rounded up (to a greater depth) and those less than .8 to be rounded down (to a shoaler depth). Features above the sounding datum, such as rocks, have in the past followed the mathematical method or a variation thereof. A revised policy that will establish a consistency for round off of rock depths below the sounding datum and of rock heights above the sounding datum is in preparation. When adopted, the decimal portion of heights of greater than .2 will be rounded up (to a greater height) and those less than or equal to .2 will be rounded down (to a lesser height).

APPLICATIONS

In the interest of maritime safety, the round-off procedure for soundings is on the conservative side and does introduce, on the average, a 0.3 foot (or fathom) shoal bias. This bias is an item that needs to be kept in mind when using hydrographic survey data as portrayed on the hydrographic survey smooth sheet. When using this data for an engineering study on sediment transport for example, either the unrounded sounding should be used or the 0.3 foot (or fathom) average bias should be acknowledged.

Additional items to be considered when using hydrographic survey data for other than nautical chart purposes are the date of the survey, the type of survey methods used to acquire and process the data, and the bottom stability in the survey area. If old NOS hydrographic surveys are to be used as the historic base line for a scientific study and recent non-NOS surveys are to be compared with this base, problems may arise.

To avoid misuse of NOS hydrographic survey data shown on the hydrographic survey smooth sheet, the method used to present these data should be understood. Depth curves are drawn on the smooth sheet based on the rounded soundings shown on the smooth sheet. These depth curves are positioned to be on the deep side of the sounding which corresponds to the specific depth curve being drawn (e.g., the 30-foot depth curve would be drawn on the deep side of a 30-foot sounding). As previously mentioned, due to rounding, a 30-foot sounding may represent a depth as shallow as 29.8 feet or as deep as just less than 30.8 feet. For nautical charting purposes and the safety of the mariner, the procedure for portraying the

hydrographic survey is conservative by design. For scientific studies where bottom contours are needed, depth curves as shown on the hydrographic survey smooth sheet may be a poor substitute at best.

CONCLUSIONS

The data collection procedures and data processing methods need to be compatible with the specific purpose for which the final product is to be used. Hydrographic data collected by NOS meet stringent standards for acquisition and processing but should not be applied without due consideration for the methods used.

Those persons or agencies desiring NOS hydrographic data (collected and processed for nautical charting) have available to them nearly 10,000 surveys. Certainly, these data are also available to those interested in bathymetric mapping or scientific studies. However, the hydrographic survey smooth sheets may be less than totally adequate for them due to the method by which the sounding data are portrayed. Those desiring unrounded data may be able to obtain it in digital format on magnetic tape for selected surveys.

NOS has been mandated to produce nautical charts and, for this end, hydrographic survey data are collected. NOS does not presently have a requirement to process hydrographic survey data in any way other than to support the nautical charting program.

CDR SCHAEFER: Do you have any questions?

LCDR KURT J. SCHNEBELE, NOS: Since you brought up bathymetric mapping, what is the status of the bathymetric mapping effort within NOS? I know at one time there were some people working on bathymetric mapping.

CDR SCHAEFER: I think I should defer answering questions on the bathymetric program if there is someone working with that program that could help me.

MR. A. M. TOLZMAN, NOS: I am assigned to the Photogrammetry Division, but very shortly here I am going to give a paper which will, I think, update that a little bit anyhow. Okay?

CDR SCHAEFER: Are there any other questions?

Thank you.

CDR VANDERMEULEN: Thank you, Glen.

BATHYMETRIC DATA REDUCTION SUBSYSTEM

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ABSTRACT

The Bathymetric Data Reduction Subsystem (BDRS) represents a new concept in bathymetric data reduction processing. The BDRS is the primary support subsystem to the Bathymetric Information System (BIS). BIS is one of eight interactive data base systems to be developed under a global control system known as the Source Data Base System (SODS). SODS will provide users with both centralized access and information manipulation capability to these various information systems, including BIS. Users will have no direct access to BDRS, but they will be able to retrieve information from BIS through SODS.

Through the use of various software programs the BDRS accepts digital data input from analog sources (such as smooth sheets and fathograms/echograms) and magnetic tape . Output from the system will consist of proof plots, track-line generation, data base access and editing, and "quick look" capabilities into the data base. New developments contained in the system are: Voice recognition digitization system which allows the input of sounding data by spoken word; digitization of fathograms and the subsequent proof-plot generation using ship's log and the digitized soundings; and, the ability to geo-section portions of the data base using circular, triangular, or polygonic searches to define user areas of interest.

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I. Introduction

The Bathymetric Data Reduction Subsystem (BDRS) represents a new concept in bathymetric data reduction processing in the Scientific Data Department of the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC). By the use of state-of-the-art technology in both hardware and software, the design of the BDRS will provide an initial influence on future data base structured systems to be developed at DMAHTC.

A. Objective

With increased emphasis on the acquisition of bathymetric data in a digital form, the BDRS will provide a means of storing, retrieving and manipulating data to provide products for the support of nautical and bathymetric charts. The BDRS will also provide a means of comparing incoming data with current or up-to-date data for accuracy and integrity. This added feature at DMAHTC will have the capability of identifying where good data exist and where more data should be acquired.

B. Development

The BDRS was developed by the Synectics Corporation (Fairfax, VA.), under contract with the Rome Air Development Center (RADC) and the Defense Mapping Agency. Synectics Corporation performed both the system requirements study and analysis/design activities, which resulted in software/hardware specifications for the BDRS. Much of the software used in the development of the BDRS had been previously developed for use on the UNIVAC 1108 mainframe. It was the job of the primary contractor (Synectics) to adapt and develop new software into a mini-computer environment with on-line (interactive) capability

and to provide the appropriate peripheral devices for each on-line function. The function of RADC was to manage the development and system implementation by Synectics. DMAHTC provided the technical expertise to the bathymetric data handling capability and function at the Center. With all three components working together, the BDRS became a unique on-line data reduction subsystem with bathymetric data base capabilities.

II. Integration With Other HTC Systems

The BDRS is an integral part of the conceptual Bathymetric Information System (BIS), which is vital to the Global Plan (Phase I) of the Source Data Base System (SODS). Its purpose is to assist in providing timely information to authorized DMA users (both internal and external) of compilation, source, and index data.

In Figure 2-1, the BDRS is the "work-horse" in this scheme. Because basic analysis and evaluations will be constantly processed to update the BIS for new real-time processing, users will have to initiate a request through the BIS where it is validated giving the requester access to the indices showing the areas of coverage, reliability of data, accuracy, and geographics.

The BDRS must maintain a flexible posture to support the various interfaces for the expansion of existing functions. These functions include software programs, digitization, analysis, and hardware operations.

Support to worldwide weapon systems is a paramount MC&G requirement at DMAHTC. Additionally, the Center receives thousands of data points, track lines, surveys, and similar data each month from naval sources, government agencies and private firms. These data must be quickly synthesized and

readied for use by the analysts for chart production. The incoming data, which have been evaluated by the hydrographic analyst, can be reduced and verified, if proper documentation accompanies the submission. It is estimated that collected source data can be readied for use quicker than some current methods using semi-automatic ADP systems.

The BDRS must also be compatible with the Lineal Input System (LIS) whose function it is to reduce analog data to a digital format. The main cost-saving here is the speed with which a nautical chart can be produced or corrected, and reduce data redundancy and manual files.

Finally, as the BDRS is integrated with other systems at DMAHTC, it is not intended to be a "cure-all" system or a substitute for all existing methods. Instead, it is a system which has been designed to apply state-of-the-art technology to MC&G areas, specifically to the hydrographic product, and to effectively reduce the total costs of producing a usable, safe, and accurate product.

III. Data Inputs

DMAHTC receives data from worldwide sources. These data fall into several general categories of hardcopy and softcopy mediums, where many hardcopy holdings predate the 20th century.

The hardcopy medium consists of survey smooth sheets, random track charts, program listings, sounding logs, and echograms. These data can be summarized as analog type. The softcopy medium includes magnetic digital tapes, and occasionally a card deck. These data can be conveniently summarized as numerical type input. A detailed explanation is given about the general inputs of analog and numerical data below.

A. Analog Data

The classification of analog data would include mostly survey smooth sheets, random tracks, and echograms which consist of lineal and point data. These data, graphically represent the physiography of the ocean floor. It is obtained by transiting predesignated lines over an area or surface, either creating a controlled pattern (survey) of sounding data or data gathering (random), which is secondary to the original mission of the vessel. Both types of data are important needless to say, but the random track data can be and often are the only data available in which to build to a nautical product. Echograms usually accompany both random and survey data. They are especially useful for verification purposes. Subsequently, all data (survey and random) must be analyzed for horizontal and vertical accuracies. The analysis is measured against a predetermined standard for accuracy. An example would be the southern oceans where the standards are usually lower due to the unavailability of substantive information which is the result of fewer ships in transit compared with the northern oceans. In contrast, the North Atlantic region has a higher evaluation standard, particularly in the vicinity of shipping lanes. Essentially, the evaluation of bathymetric data is relative to a geographical region and the density of available quality data in the same region. The BDRS is designed to sort and track these various parameters for data evaluation.

B. Numerical Data

Numerical data are sounding logs, digital magnetic data tapes, or single point positions and soundings. Presently, much of these data must be digitized and manually compared to the associated source such as a ship's track for evaluation. The advent of the BDRS can greatly simplify this process and make it less tedious than current methods allow. A comparison is made and finally evaluated with

visible overlays plotted to the scale of the track or echogram. This procedure immediately illustrates whether the data are valuable for storage purposes. Over the last few years, much of the data submissions to the Center are in a digital format which make it easier to plot and verify, after the header information has been deciphered, if the data package has been properly documented. Over the years, DMA has had good success with the data it has received from the U.S. Navy, petroleum companies, National Ocean Survey (NOS), Naval Research Laboratory (NRL), and the Naval Oceanographic Office (NAVOCEANO). The merchant marine community is also an excellent source of information; however, most of their submissions are through conventional means (hardcopy) and random in nature.

Lastly, Figure 3-1 shows a simplification of the data types received and how they are interfaced within DMAHTC to support the worldwide users of hydrographic information and other specific data.

IV. Data Outputs

The BDRS will be used as a support tool primarily for the Scientific Data Department at DMAHTC. However, its information can be used by anyone requiring access to bathymetry in a digital form.

Basically, the BDRS has outputs of four types. They are: plots, graphic displays, summary reports, and magnetic tape files.

A. Plots

Plots are any output which will eventually be produced from a readable tape on a Xynetics or Calcomp Plotter . Plots of this type include: Proof plots for verification against existing data plots, General Bathymetric Chart of the Ocean (GEBCO) track line plots of ship tracks registered while soundings were being recorded, and plots of a geo-sectioned area contained in the data base (geo-sectioning will be described later in this paper).

All plots output by the BDRS provide the analyst with a reference sheet of what data are contained in the BDRS data base. Plots provide a vital support tool for the preparation of source information packages, which are the first step in producing a new chart.

B. Graphics Displays

The BDRS also can output data in the form of a "quick look" display of the digital data. This can be performed on one of three CRT display devices. This "quick look" feature allows an analyst to examine quality of data available in a region, without having to wait for a hardcopy output to be constructed. The BDRS also allows access to any textual or source identification information that a unique document identifier has associated with it. The unique document or data holding is referenced by what is called a document number. This is an account number, which is assigned to a unique group of data when it arrives at the Center. The BDRS can output all document numbers in a region and describe the area encompassed by each document number.

C. Summary Reports

Whenever a conversion, or any other batch process takes place on the BDRS, a record of the transaction is stored and can be retrieved and easily printed using the line printer. Information contained on these reports identifies all old and new parameters that were involved in the conversion process. In addition, when a retrieval of the BDRS data base is required using a document number or geographics, a summary report is produced to summarize what a user created. This feature can be considered a supervisory function of the BDRS.

A dump of all data blocks, entered into the data base or contained in a geographics file, can also deliver a summary report on the line printer, allowing the user to do a sounding-by-sounding check of the data.

D. Magnetic Tape Files

A file can be dumped to magnetic tape for input into other system routines. Output is executed using BDRS operating system commands. Digitized data can also be output to tape using a software routine, which outputs an octal dump of the data.

V. System

A. Hardware

The BDRS consists of predominately off-the-shelf equipment and can be acquired from vendors by way of their individual product lines. An illustration of the BDRS hardware is given in Figure 5-1.

The computer used for the BDRS system is a Data General Corporation (DGC) Eclipse C-300 with a 92 MB Data General Disk Unit. The disk is the mass storage device on the BDRS and contains all operating system software, user generated systems software, and data base information. The Eclipse is a 16 bit machine, 128k word core memory, with memory capacity to 256k words with optional map. Two 9-track Data General magnetic tape drives are also linked to the main Central Processing Unit (CPU) for tape input/output functions.

The BDRS supports two Data Automation Digitizing Tables. The first, known as Station 1 (See Figure 5-2), consists of a digitizing table, a Data Automation standard 3-inch field of view cursor, with a 16-key keyboard and a Tektronix 4010 graphics display terminal. The table has a free-cursor electronic

digitizing system which provides a measurement accuracy of ± 0.005 inch over an area of 60 inches in the X direction and 42 inches in the Y direction. Measurement resolution is 0.001 inch with repeatability of ± 0.001 inch. The keyboard is used primarily for depth entry, but also can be used for editing and deleting functions.

The second table, known as Station 2 (See Figure 5-3), is basically the same unit as Station 1, except for one variation. Station 2 has a Threshold-500 voice entry system with a visual feedback display cursor. The Threshold Technology, Inc., system is an electronic speech recognition system, which automatically recognizes up to 32 spoken isolated words of up to 2.0 seconds duration each. This system is a prototype device which will be used as an alternative to the manual depth entry keyboard. This device can be trained by up to 99 users and serves as an aid to rapid depth entry input. The visual feedback cursor (developed by Data Automation Company) displays the spoken numeric, in the order of entry, on the cursor itself and allows for checking voice entry before the actual entry is recorded in the system.

Two automated drafting plotters are associated with the BDRS, but are not directly connected to it. One is a flatbed plotter manufactured by Xynetics Corporation (Model 1101). The other is a drum plotter manufactured by Calcomp Corporation (Model 936).

Peripherals contained on the system (See Figure 5-1) are a Centronics 101A Line Printer, a Data General 6012 CRT (which is used as the master terminal), and two dedicated devices, Data General 6052 Dasher terminal and a Tektronix 4014 Graphic CRT, which are used for data base operations only.

B. Operating System and Related Data General Operating Components

The operating system of the BDRS is Data General's Real-Time Disk Operating System (RDOS). It is a mapped system, which means it can run two user grounds (foreground and background) simultaneously. The primary interface between a user at the system console and RDOS is Data General's Command Line Interpreter (CLI). CLI is designed to accept command lines from a system console and translate them into operating system commands.

The BDRS is supported by Data General's INFOS. INFOS is a file management system, which will maintain the BDRS data base access and control capability. INFOS is intended to provide a concise, and flexible method for the creation and processing of sequential files, random files, indexed sequential files, and data base files.

Other system features of the BDRS include: Data General Text Editor, Data General Octal Editor, Data General Extended Arithmetic Processor, Fortran IV and Fortran V compiler, and power fail detect and automatic restart feature.

C. Software

The BDRS software can be described as being made up of three subsystems or modes with several special purpose routines. The three subsystems are: digitization, batch, and data base.

1. Digitization

As can be seen in Figure 5-4, the digitization process can input several types of information in several different ways. During what is called the initialization mode, chart information is entered and recorded for use later in the Batch conversion process. Once this information is entered, the chart, echogram

(fathogram), or smooth sheet is registered to the table. When a chart is registered it is said to be relatively referenced to the table X/Y coordinates. From 2 to 10 points can be referenced (the usual being just 4 points). These reference points are flagged by a geographic coordinate which later on in the batch subsystem can be directly merged with the X/Y data to produce a geographic file (GO). All X/Y positions on the table are entered via the two cursors at Station 1 and Station 2 (See Section V-A "Hardware"). Two methods exist on the BDRS for depth entry. Both Stations have the ability to enter depths manually via a keyboard assembly. Station 2 has a new function (as applied to bathymetry) of allowing depth entry via a spoken word. Station 2 (See Figure 5-3) has a Threshold Technology Model 500 voice entry terminal. Once an operator has trained his or her voice on this system (training means speaking in a consistent manner into the system's microphone and allowing a digital vocal pattern to be defined), an entry of depth can be registered both visually and on disk.

The digitization processes' most important manner of operation is known as Master Mode. This mode controls all inputs or operator commands selected by the user. Five subfunctions exist under master mode and the majority are accessed via the digitizing tables' 5-pushbutton cursor. Three of these subfunctions control the input of data (Trace Mode, Depth-entry Mode, and Discrete Point Mode). Trace Mode inputs any linear or continuous feature such as shoreline, contour, or echogram trace. Trace mode also inputs any feature which consists of a continuous line segment. Depth-entry Mode allows the user to input independent depths using either the manual entry system or the voice entry system. Discrete Point Mode allows the entry of individual grid ticks where they can be used for reference to a grid or projection type relating to the source material. Two other subfunctions exist on the BDRS which allow corrections or modifications

to be made. The first is known as review mode which allows the review or examination of everything entered via the previously described input functions. A window relative to the area positioned by the cursor is set up, and all entries within this window are flashed on the Tektronix 4010 CRT for visual verification of all entries. The other subfunction used for verification or modification is the edit mode. This mode allows the operator to delete, change, or modify any feature such as a sounding entered during any of the first four modes.

Outputs from the Digitization process are in the form of three files (See Figure 5-4). The Data File (DF) holds all of the X/Y data recorded by the cursor. The Header File (HF) holds all header information that describes a unique feature. The Index File (IF) holds all source information that will be used in the batch conversion process. These three files can all be deleted using RDOS (See Section V-B) commands from the Background Master terminal.

The BDRS also has the unique ability to digitize an echogram and allowing it to be converted in batch to a file that can be entered into the BDRS data base. When digitizing an echogram (depth verses time analog source), trace mode is used and the depth curves contained on an echogram are recorded. When a change of scale or when a long echogram has to be reregistered, a new file is created (FF-Fathogram) which holds all change information.

As can be seen in Figure 5-4 a job which has already had data entered can be reentered, and new data can be appended to it. When this happens the job must be reregistered and checks must be made against residuals to assure that the same chart has the same "day one" registration. Residuals are error parameters which tell how far away from the original (day one) registration a chart is the second or third time it is used. Ideally, day one registration should show zero residuals, and day two and after should be no greater than .005 inch off (residuals are measured in units of .001 inch).

2. Batch

The batch subsystem provides the interfacing of the digitizing subsystem to the data base subsystem. Each function can be described as being standalone, meaning it performs one function and one function only. General categories of all batch subsystem functions are: Plotting functions, conversion functions, and input/output batch routines. (See Figure 5-5 for a diagram of batch subsystem data flow).

When plotting functions are defined, reference is made to any routine in batch which produces a Xynetics or Calcomp plotter readable magnetic tape. These routines include Proof Plot (used to plot an overlay of previously digitized soundings), Scaling Echogram (used to plot an overlay of a previously digitized echogram/fathogram), and Plot Driver (which is used to create a Xynetics or Calcomp readable tape of the previous two routines). A routine called GEBCO Track Line is also contained in subsystem batch and is used to plot "track lines" or ships course across the ocean.

Conversion routines used in this subsystem cause a file or files to be changed over to a new format. The most important of these is a routine called Table to Geographics conversion. When a job is completed on one of the two digitizing tables, the files created are said to be in table (X/Y) coordinates. This routine takes the table file and converts it to a geographic file (latitude, longitude, depth). This is an important step because the BDRS data base is stored in geographic coordinates. When an echogram is digitized another routine is run which requires an echogram table file and the previously entered ship's log file. These two are merged, and a geographic file is produced. This file can now be entered into the data base in the same way as any other geographic file. Other routines contained in the batch subsystem include Geographics to Table

conversion (used to create a new table file from a previously created geographic file), Depth Adjustment (used to filter depths in dense data regions), and Datum Shift (which converts from one datum to another).

Input/output batch routines are also used to capture data previously created on other systems. Systems to be interfaced with the BDRS are the Lineal Input System (LIS) (the data digitizing system used in the Hydrography Department at DMA), and UNIVAC 1108/81 holdings of previously digitized soundings, held on tape and accessed off-line by batch processes. The BDRS batch subsystem can also transfer files to and from magnetic tape. The output from this routine is an octal dump which can be used on the system.

3. Data Base

The BDRS data base subsystem is designed to create, update, and maintain a viable holding for bathymetric data. The data base utilizes Data General's INFOS file management system. The design within the data base consists of three unique modes of operation: Master Mode, On-Line, and Batch (See Figure 5-6 BDRS DATA BASE DATA FLOW).

Master Mode allows a system supervisor the capability to assign a log-on password and read and or write privileges to the data base. The above parameters can be deleted or modified to accomodate the needs of the user. The system supervisor can also reinstate or delete those documents flagged logically for deletion during the on-line process. Basically Master Mode is a tool designed to insure data base integrity.

The On-Line Mode is designed to input document source description records and is capable of random geographic queries of the data base. To support this function the Data General (DG) 6052 and TEKTRONIX 4014 graphic CRT's are used, respectively (See Sec. V-A "Hardware"). The user can input, review/modify, or delete source information via the DG 6052 CRT; remembering from master mode he/she was assigned a password to read and/or write privileges to the data base. To input a document source the user defines the geographic area (bounding rectangle) and a 10-digit document number. The document number is assigned to any data (analog or tape) which is received by the Scientific Data Department for catalog purposes. The source descriptive record(s) consist of unique parameters defining the type and quality of data associated with the document. These values are entered and can be reviewed or modified. If modification is desired, the user can update any parameter as required. The deletion process allows the user to logically delete the entire document or a particular sheet(s) of that document. Only the system supervisor can physically delete any data from the data base. This is another tool to insure data base integrity.

Continuing with on-line, geographic queries can be performed by both terminals. Utilizing the DG 6052 the user queries the data base by inputing 2 to 8 points. The retrieved data displays the document(s) for review. Another feature is point search. This allows the user to define an exact location (latitude and longitude) to search the data base for one data value. This is extremely useful when questioning the validity of a sounding value. The Tektronix 4014 allows the user to geographically query the data base and display the retrieved data graphically. The graphic display consists of the ship's track as stored in the data base and referenced by the geographics used for that query. The retrieved data can be used as an output file to be plotted for the user.

The Batch Mode of the data base subsystem allows the user to interactively load, query, and logically delete data from the data base. The load process requires a BDRS standard geographic file, the document, and respective source descriptive parameters. The standard geographic digital file is transfered with its respective source descriptive parameters into a hierarchial data base. A query of the data base is accomplished by document or geographic retrieval. The document retrieval searches the "geographic" data base and displays the document(s) and the associated source descriptive parameters. The geographic retrieval allows the user to query the data base by two methods, geographically and logically. A logical query can be by a ship's name and or data evaluation. (See On-Line Mode). Geographic sectioning of the data base retrieves data by a circular, triangular or polygonic method. (See Section VI C). The output from geo-sectioning is plotted on the Tektronix 4014 graphic CRT in the form of track lines. A list of all documents contained within the defined geographical area will be displayed. This display can be transferred to a BDRS geographic formatted file. The final output of a geographic query is used to produce a computer plot via the Xynetics or Calcomp plotters. Finally the data base Batch Mode allows for logical deletion of a document (See Master Mode). A report is generated from the line printer to provide the user with a hard copy summation for each request during the Batch Mode.

VI. Highlights of the System

A. Voice Recognition Digitization as Applied to Bathymetry

The BDRS allows the input of soundings by a different method than has been previously employed in a digitization process. Station 2 (See Section V-A "Hardware") is connected to a Threshold Technology, Inc - Model 500 voice data entry terminal. This hardware unit allows a user to input independent numeric data by spoken word. Once the values of a sounding are spoken into the machine, a user can enter the sounding into a user defined file as a X, Y, Z value. Numeric values are both displayed back to the user on the data entry terminal as well as on a special Data Automation LED display cursor. Having the values displayed in this way allows real time checks of each sounding before it is entered into a file. The voice system has several advantages and disadvantages. One advantage is that the operators hands are free to hold the cursor at a static position, which allows for a more accurate entry of the X, Y position. This system also allows up to 99 different voices to "train" the system. A disadvantage of the voice system is that it is an early version of Threshold's voice system, and it does not accept spoken words as fast as some of the later models. The system can be field-upgraded with new hardware, which will allow it to handle a much larger vocabulary and to be much faster. For purposes of the BDRS, however, the voice entry system allows an alternative to manual entry, and it does allow reasonably fast data entry.

B. Echogram (Fathogram) Digitization and Verification

A very significant development of the BDRS is the ability to digitize an echogram, convert it to geographic coordinates, and examine the recording ship's track by displaying it on a CRT screen. An echogram shall be defined as any graph

that contains depth versus time axes and a copy of the recording ship's log of geographic fixes, loxodrome bearings, and ship velocity changes. Up until this point, all previous abilities to digitize echograms had output X, Y depth formats. The BDRS produces geographic - depth positions, and because of the geographic nature of the BDRS data base (See Section V-C "Software"), echograms can be entered directly into the data base, and plots of this data can be made using the BDRS Geo-Sectioning routines. This is a significant improvement over previous hand calculations that took place when utilizing an echogram (fathogram).

C. Geo-Sectioning of the Data Base

Geo-Sectioning (geographic) is defined as the ability to access a data base by defining geographic coordinates (in the BDRS one can define 2 to 8 points) or bounds and by outputing all information contained within this specified area to a display device. The BDRS allows a user to define a circular section (2 points), a triangular section (3 points) or a polygonic section (4 to 8 points) of anywhere in the global data base and to output it to a CRT screen or plotter readable coordinates. The major emphasis here is on the phrase "anywhere in the global data base" because the BDRS, for the first time can section data on either side of the prime meridian and north or south of the Equator. This is a breakthrough development, and Synectics Corporation should be given full credit for developing the algorithm. The BDRS data base is geographic in nature and because of this the sectioning routine outputs data in the form of a geographic file. This file can be input into many other BDRS batch routines and converted to a plot of the sectioned area. The plot can then be utilized as a product in support of the production effort of nautical charts.

VII. Conclusion

The Bathymetric Data Reduction Subsystem (BDRS) is one of the newest interactive data bases in the Department of Defense. The BDRS was conceived for the support of weapons systems that require worldwide hydrographic data. Being interactive is cost-saving in that real-time turnaround permits rapid editing and modification of the data base. Moreover, advanced editing and updating features allow data entered to be kept at maximum accuracy and integrity with minimum redundancy. With such an accurate data base, mission goals of DMAHTC can be met more rapidly and with improved accuracy.

It is necessary to note that the BDRS is a prototype unit and is still under testing for compatibility with present DMAHTC support applications. At present the system seems to fit in well with the Center's current compilation and source package preparation flow, and it appears to be a workable application of automation at DMAHTC. The current system will have to be expanded, however, with respect to memory, as more and more data are input into the system. This should be no problem because of the Data General Eclipse C-300's compatibility with new peripheral equipment (such as disk units) and software application programs.

In conclusion, the BDRS is a fine mixture of components which perform a specific function relative to bathymetry. It has a place at Defense Mapping Agency Hydrographic/Topographic Center and will influence the creation of future data base systems at the Center.

VIII. ILLUSTRATIONS

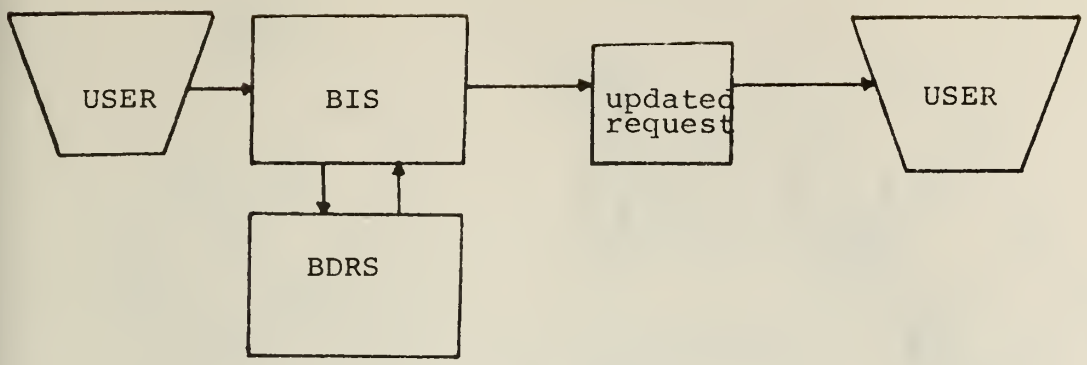

FIGURE 2-1 BATHYMETRIC INFORMATION SYSTEM CONCEPT

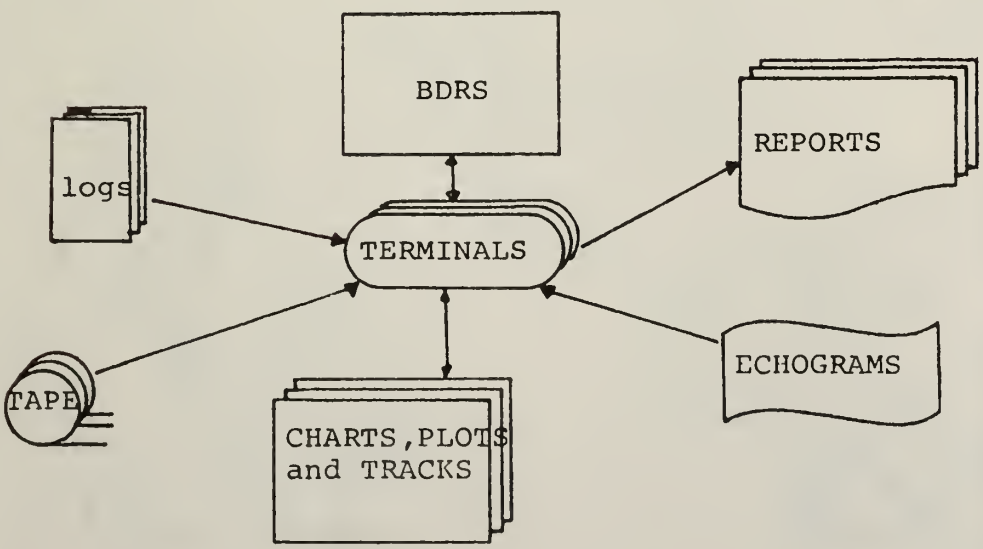

FIGURE 3-1 BDRS SIMPLIFIED INTERFACES

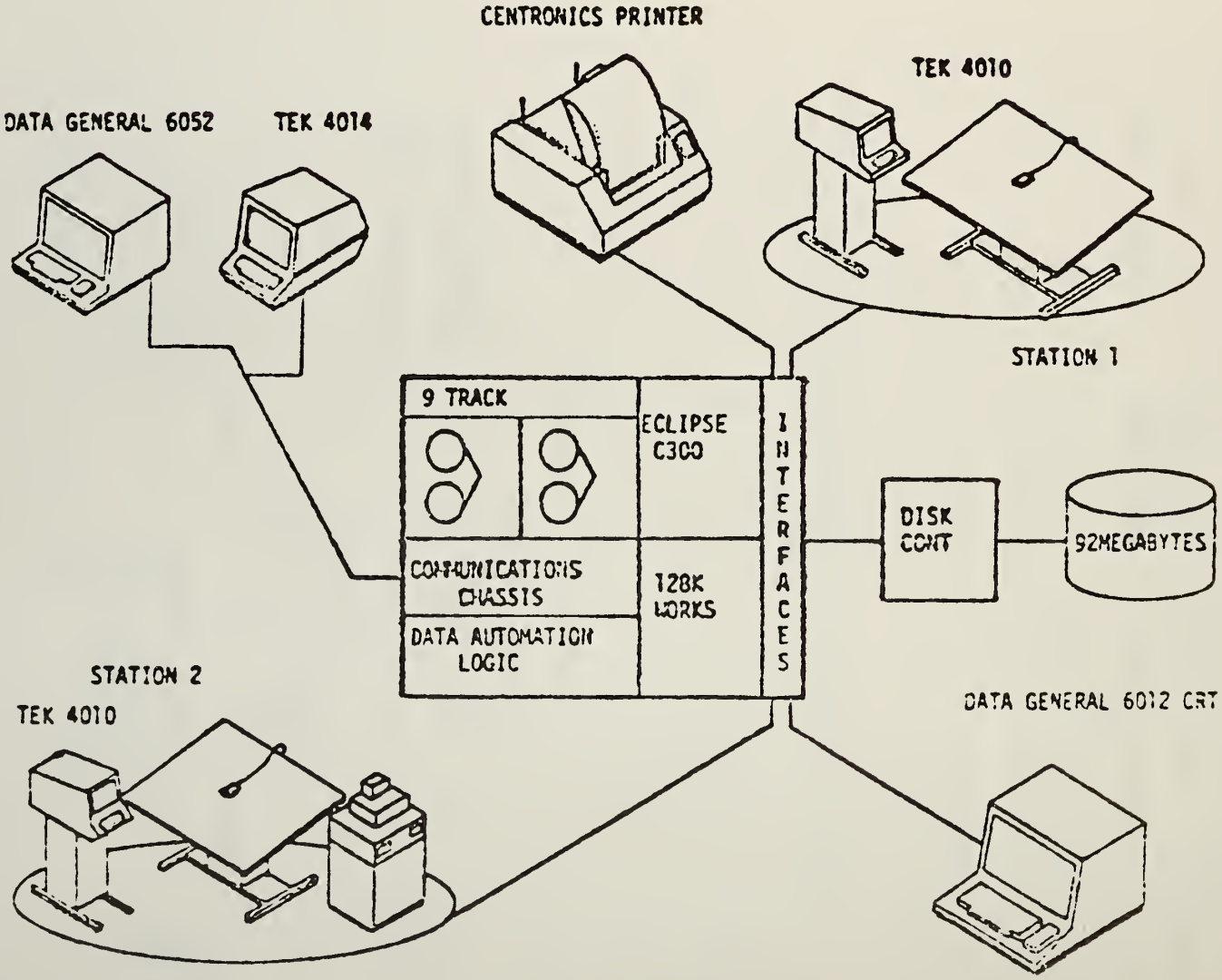

Figure 5-1 BDRS Hardware Configuration

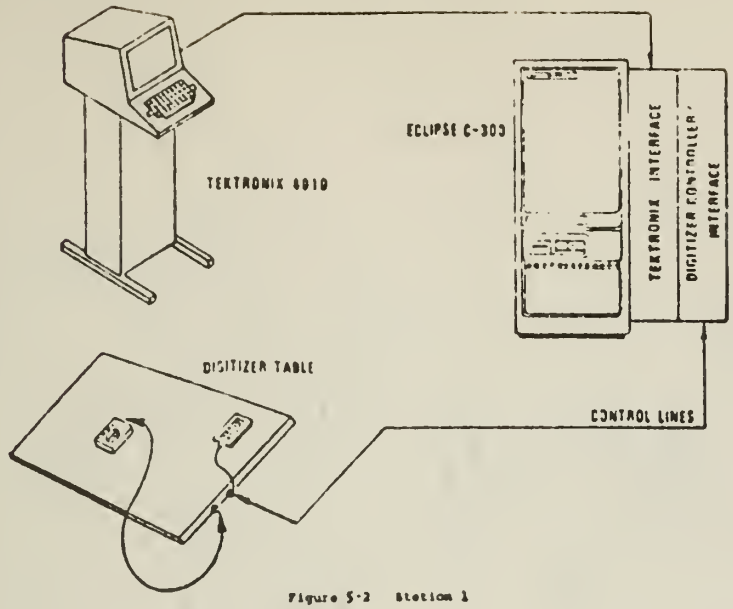

Figure 5-2 Station 1

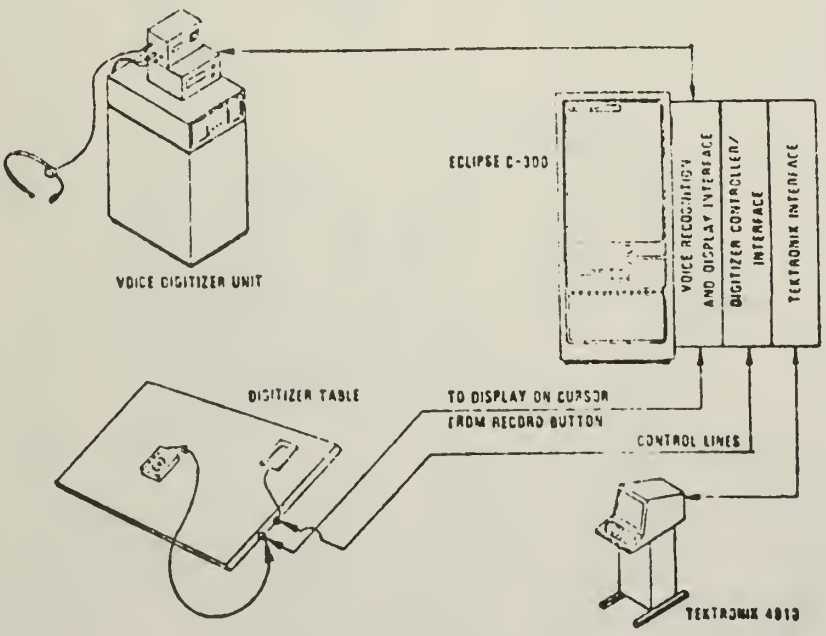

Figure 5-3 Station 3

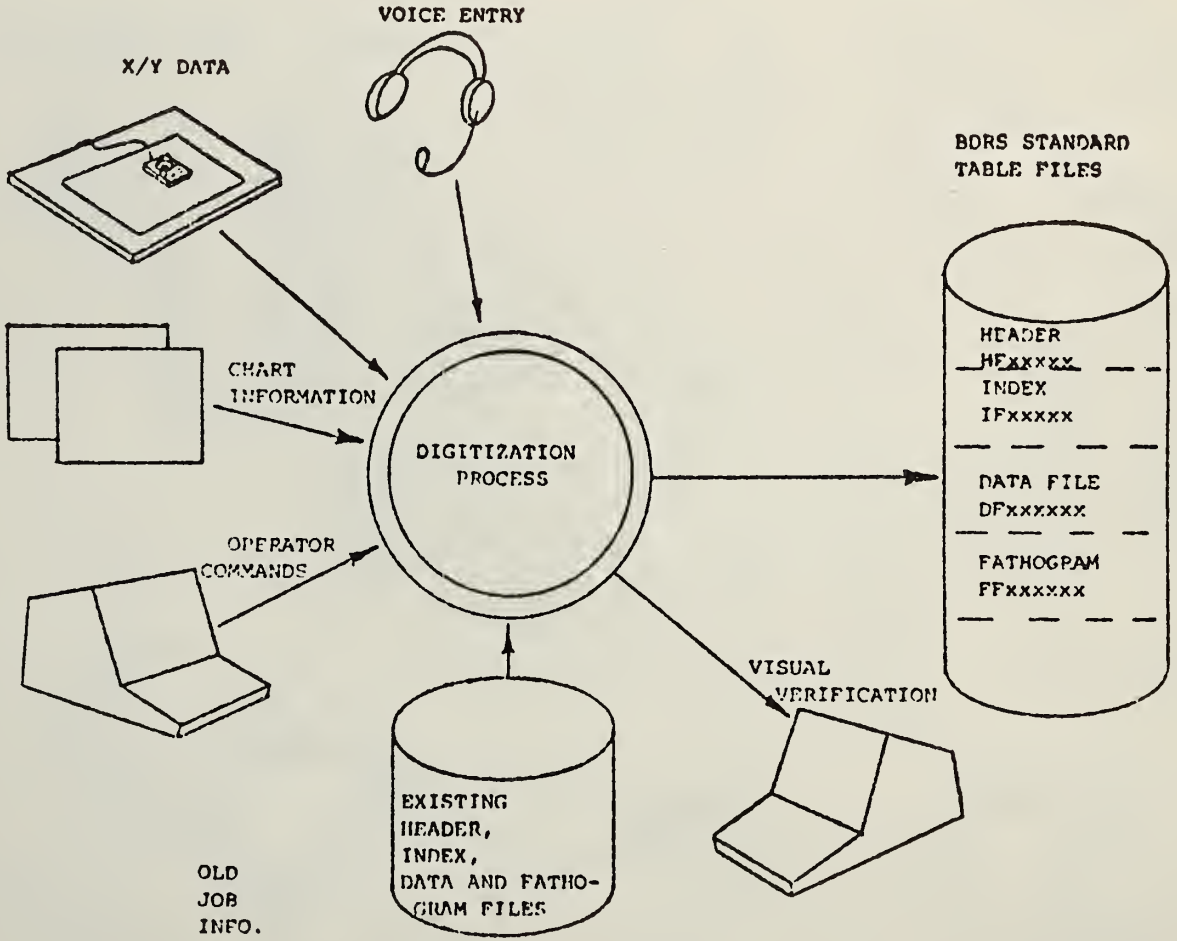

Figure 5 - 4 Digitization Input and Output

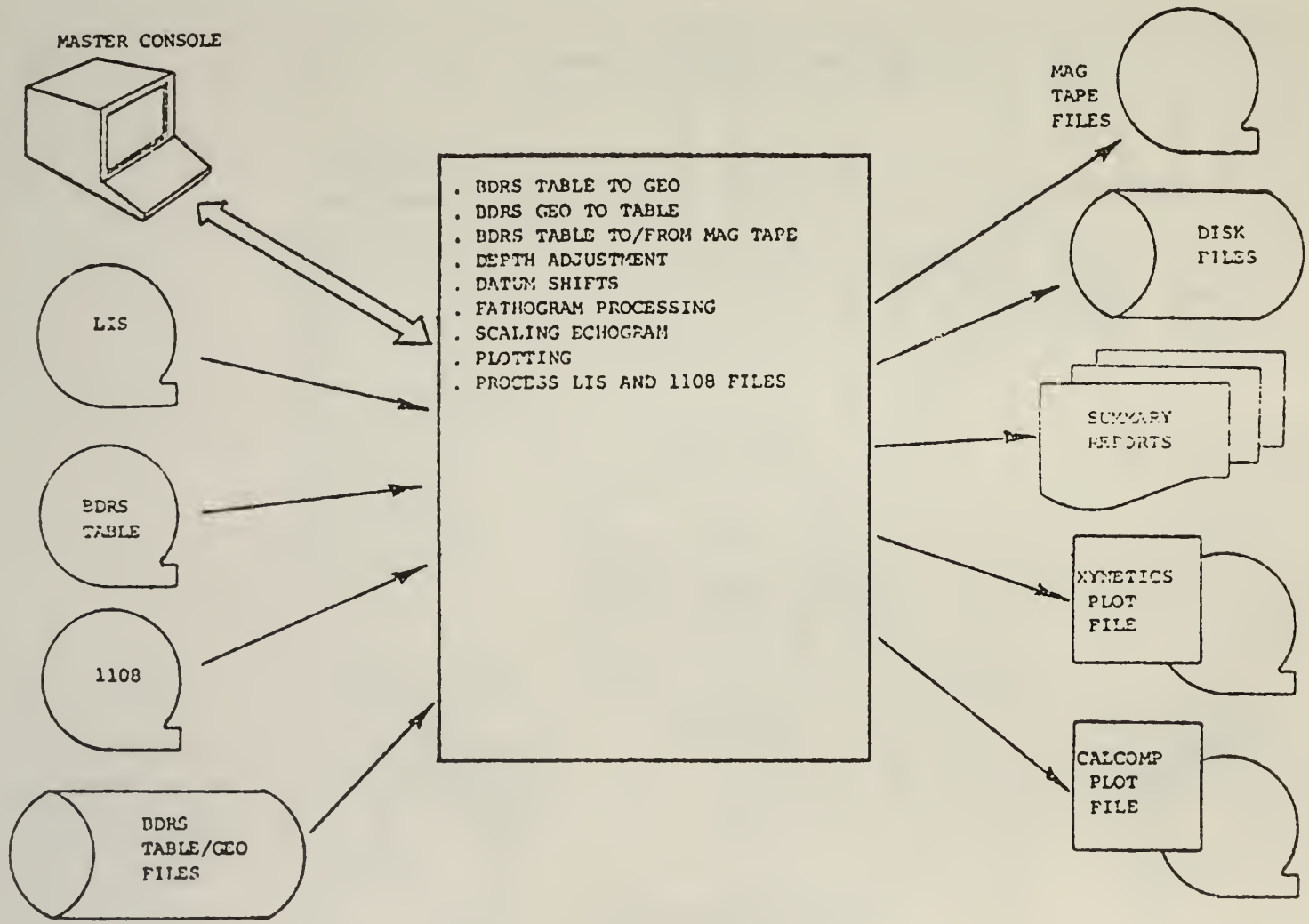

Figure 5 - 5 Batch Subsystem Data Flow

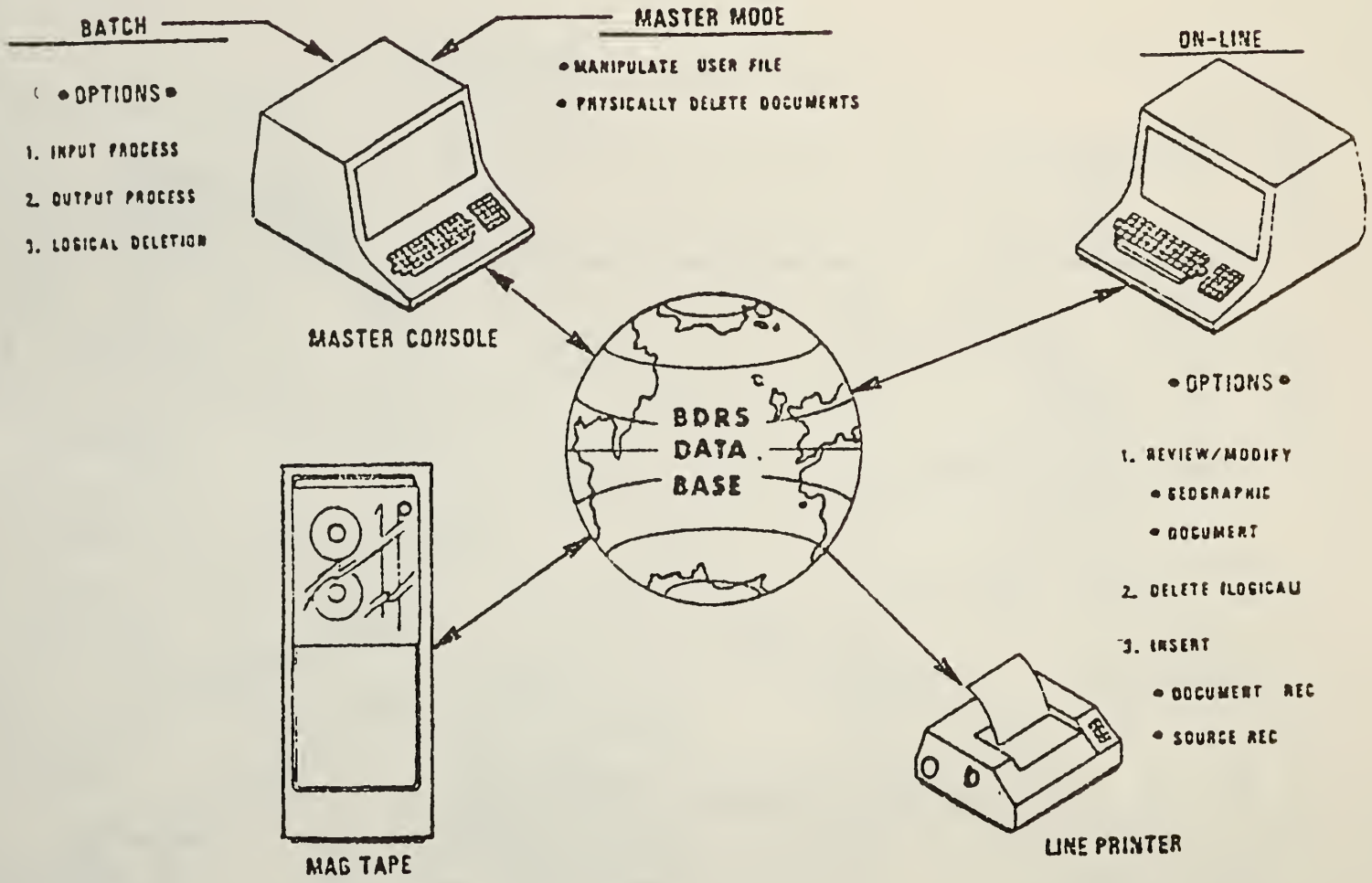

Figure 5 - 6 BDRS Data Base Data Flow

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JIM MORAN, DEFENSE MAPPING AGENCY: Any questions? Yes, sir.

LCDR GREGORY BASS, MARINE DATA SYSTEM PROJECT: I was just wondering, how large is your BDRS data base?

MR. MORAN: Currently we have 15 and a half million soundings on tape, and we are going to convert that into a disk format. That data currently exists now on tape, and as soon as we finish our operational test and evaluation, then will go into loading the data base.

That data will not fit on that 92 megabyte disk drive at the current time, but then it will take quite sometime to load 15 and a half million soundings. So part of our upgrade is we are going to have to get another disk drive.

LCDR BASS: Do you have more than soundings? Do you have topo?

MR. MORAN: No, sir, we don't. Strictly bathymetric data.

LCDR BASS: When you do get your data base loaded, do you plan to update the data base interactively?

MR. MORAN: As new sources come in, sure.

LCDR BASS: Using the Techtronics, the table?

MR. MORAN: Right. See, that's why on the blue terminal 60/52, it allows one to modify or update the data base as new data comes in and you can change the parameters.

If an incoming source is giving a class code of one, which is relatively good data, and then over the years that new data has come in and outdated the old data, then we can give that a lower classification code and change data as required.

LCDR BASS: This outdated superseded data, do you plan to save that?

MR. MORAN: I don't know what the plans are right now. John Lanier might be able to answer that question for me.

I would like to introduce John Lanier. He is one of our co-authors and life-saver.

MR. J. LANIER, DMAHTC: I think Jim did a fine job.

As he said earlier, I had a hard time finding the hotel. Please forgive me for being late.

At DMAHTC, we don't destroy data per se, particularly if it's survey data. What we will do is give it a lower priority.

Now, in some cases of random data, to save space obviously what we will do is evaluate the data, we will digitize it, microfilm it, and at that time make a determination of whether it should be destroyed or stored in the record center. But we don't destroy, per se.

Now, when new data comes in, as I said earlier, that data would be given a higher priority based on its evaluation of horizontal and vertical control.

And based on this determination, it is then stored in the data base, the data that was used previously in the same geographic area is then removed from the data base, so to speak, given a lower priority, and stored in the Federal Records Center. But we don't destroy, per se.

Thank you.

CDR VANDERMEULEN: There was a question there.

MR. BILL BARNES, NOS: Several questions. One, have you plotted interpolated curves from your digitized data?

MR. MORAN: No, we haven't.

MR. LANIER: Can you just sort of clarify?

MR. BARNES: There seems to be a smooth curving from, say, bathymetric soundings.

MR. MORAN: We are working on the contour plotting system, which is a software package, and we are working on that right now. But currently we are more concerned with, I guess, the actual sounding latitude and longitude and depth right now, unless John would like to add --

MR. LANIER: We have done some experimental work with the smooth curve. You mean the contours, I guess?

MR. BARNES: Right.

MR. LANIER: We have done a little experimentation with that. As a matter of fact, we have produced a bathymetric chart, bottom contour chart -- I think it was on 805 or 807, but, in any case, using the experimental contouring program -- where we did smooth. However, it wasn't done completely automatically. There was some manual manipulation. And that was primarily because we were using a lot of the random soundings.

And random soundings -- well, I don't know if you are familiar with it, but they don't always agree, particularly at your crossings, as you would a beautifully controlled survey. Strictly on an experimental basis.

Now, as Jim mentioned, we are in the process of improving the contouring program and making it more applicable to production and inactive with the BDRS, Bathymetric Data Reduction System.

MR. BARNES: I assume you are digitizing things such as shoreline or hard features. How smooth have you been able to reconstruct this in your plots?

MR. MORAN: In our system the bathymetric data which we are concerned with is primarily the latitude, longitude and depth. The lineal input system, which is in the hydrographic department, is more concerned with the shoreline data for approach and things like that.

John, you want to expand on that a little bit?

MR. LANIER: In the area of bathymetric data, which is our primary concern, the BDRS does allow us to digitize, and we can smooth. Of course, that would depend on the scale.

However, our primary concern is hydrography and the shoreline, and that NAV AIDS are basically secondary to us.

Another department within the Center handles that particular area but they can also smooth. That's our hydrography department.

MR. BARNES: I'm going to ask what is probably an embarrassing question for both agencies, but is there any liaison between your effort and our automated information systems?

MR. LANIER: Where are you from?

MR. BARNES: NOS.

MR. LANIER: Yes, there is.

MR. BARNES: There seems to be several people going in several different directions. At this point it would seem there should be some type of cooperative effort.

MR. LANIER: There is liaison. I am not in that particular loop, but I do know that our people at DMAHTC have been working with the NOS people out in Rockville. Particularly on the contouring bit.

As a matter of fact, to give you an example of what we feel is complementary type of effort is that when we were trying to decide whether we were going to put the automated sounding contour program on a Univac or mini computer, we took your needs and your capabilities into consideration. And through our effort, three or four months late, but we did.

Now, the BDRS has been back and forth. The agency went through some consolidation. However, DMAHTC is committed to this Bathymetric Data Reduction System and also it is committed to working with other agencies who have a related need for our data, and that includes NOS.

Was there another comment?

MR. BARNES: No, that's all I had. Thank you.

MR. LANIER: Okay.

LCDR RICHARD A. SCHIRO, NOAA: 15 million soundings seems very small for your area of responsibility. In this system, does that represent the sum total of the amount of your bathymetric data?

MR. LANIER: Total soundings?

LCDR SCHIRO: Yes.

MR. MORAN: No.

LCDR SCHIRO: So then --

MR. MORAN: In addition, we have soundings that are still in an analog form that are given to the cartographers to use as a source package.

LCDR SCHIRO: So what is the purpose of the system, then; just to keep the most used number of soundings, then?

MR. MORAN: We want to build a real time world, as far as queries. The cartographers have to go to document cards and files to look up source information. We want them to be able to sit down at a terminal and get that data within minutes.

Also, instead of retrieving data, say, from the archives of the Federal Records Center or from holdings at our agency, we can produce all that data in one plot at that given scale and projection for the cartographer. Instead of sending up a group of sheets for one area, we can send up one plot. I believe that is the direction we are going to.

LCDR SCHIRO: Yes, but what I am saying is does the system represent the sum total of information that you do have or is the subset of it? And if it is a subset, what method do you use to determine which of those soundings from the larger mass of soundings that you put into the system?

MR. LANIER: Okay. 15 million, as Jim mentioned earlier, would be the approximate number of sounding we have in our data base. Now, these soundings represent, just to go back a bit, data that has been digitized, hard copy data received by the Center which has been digitized, and put into a digital format. Primarily this data is on mag tape, and we are in the process of loading a lot of this data into the system.

Now, as you may or may not know, our holdings go back to Captain Cook's days, you know, of rough soundings. But at some point we have to determine a break point. In other words, the means of inputting data -- well, the resources are pretty limited. So, therefore, we have to determine what is important to us.

I'm not trying to skirt your question. I think I know what you're trying to say. We are loading data. We haven't determined how far back on hard copy

we will digitize and load. It's very difficult because a lot of the information we are receiving nowadays is good data, it's in a usable format, namely a digital format. And this system is really designed for expansion of digital data coming into the Center.

Now, to give you an example, we have hundreds of surveys that are in hard copy. Now, we have to determine -- and we do have other technology and other systems coming along the way that is going to support us. But when you talk about digitizing surveys, its like almost re-inventing the wheel all over again. And you have to really look at costs associated.

So as I said, we do have some technology coming down the pike which would help us to input this data. And it would be most cost effective for the users, as well as for the Center.

I could not give you a total number of soundings that we have in our data base, but it's in the hundreds of millions.

LCDR SCHIRO: I am trying to understand what the criteria was for determining what past data would go in the system and then what future data flow would be put in the system and what would be the criteria in making the decision whether or not it was put in or not.

MR. LANIER: Mostly surveys, just to be specific and short, that are hard copy right now would be our number one priority. Then areas based on need of the Navy and the merchant -- well, merchant community would also be given a lower priority. But that type of data is the kind of stuff that we want to put in.

Now, once we have our data flow developed, then all new or incoming data, say, as of 1980, is thoroughly evaluated and automatically a program for the BDRS, based on its priority, as we mentioned earlier; surveys versus random data.

LCDR SCHIRO: Thank you.

MR. LANIER: You're welcome.

ADAM J. KERR, CANADIAN HYDROGRAPHIC SERVICE: I was a bit mystified by your use of the work analog. I wasn't quite sure what you were referring to when you were talking about analog there.

I wondered, when you digitize information, whether you classify it concerning its accuracy or reliability and whether you put a qualification factor into your data bank. Because when you are going to analyze it later on, you obviously need some reliability indicator.

And then, as one of your sources of input in an agency such as yourselves, I can only assume you must take in foreign data and that you probably take it from foreign charts. And one of the questions which have been before people that get involved in these large digitizing operations is whether you should go back to the source data or whether you should accept the work of cartographers over many generations in bringing that up to a chart.

When you have a foreign chart, it's gone through a great deal of analysis. And, in fact, many charts will have indicators on the charts, the soundings might be in slant line as opposed to upright to indicate a quality of data or an age of data, and I was wondering if your pretty girls were in the business of analyzing which was which or whether it was routine operation.

And then, having assumed that you have decided that one sounding is better than another one, I think you said that you never throw out data, so that you must have some system of storage in which you actually stack data concerning a geographical point. You must have several data and you stack them, presumably, on levels of reliability; the first line one is the one you are actually going to use, or something like that.

And then another source of data, in our experience of getting data from oil companies and so forth, it doesn't always come to you in what we call digital form. It sometimes comes in contour form because they want to obscure the actual source of the information. How do you handle that?

So there's a whole bunch of questions for you to answer.

MR. MORAN: Which one do you want first?

Basically, when the file has been digitized and it's being loaded into the data base, you must build what we call a source descriptive information for each sheet of digital -- for each sheet that is digitized, there is a little history sheet on that, and that lists the quality of the data, the media of the data, the types of navigation that were used to record the data, the security classification, the ship's name, source I.D. We have this 20-character source I.D. which allows the cartographers to know a certain amount of information about the quality of that data.

So not only are they looking at broad, digital data, but they are looking at the quality and type and the way it was retrieved.

John, I think, is going to have to answer a couple of the other ones.

MR. LANIER: You threw a lot of questions at us, but let me start at the first question.

I think the first question you had was about the analog. Now, when we talk about analog data, we are primarily talking about contour information, contour data. You know, the squiggly lines and that type of thing. That's what we mean when we say analog. I don't know if that answers your question in one word.

MR. KERR: It doesn't mean actual sounding records? You don't go right down to sounding rolls or -- what do you call them -- echograms?

MR. LANIER: Echograms? Well, yeah, that too. But primarily in the case of analog, we are really mentioning data which has been reduced to contours.

Now, I guess secondarily you could speak of analog data as being echograms or profiles, but here we are talking primarily about contours.

Now, the other question you had, I think, dealt with reliability, I believe, of information.

MR. KERR: Qualification of the data in terms of reliability.

MR. LANIER: You have to keep in mind that when we talk about BDRS and the Bathymetric Information System, we are really talking about a twofold system. You are looking at almost an end product for getting the data into the system, manipulating data.

However, there is a large process that precedes that, and that is primarily the hydrographic analyst or the oceanographers or cartographers have to give this data a good going over. And, as I said earlier, what we are doing is primarily evaluating that data based on its source, and we are not just arbitrarily saying, the Canadians do better work than the English or anybody else. But we have a system of criteria and system of standards. And some of this comes with experience and some of it is a comparative type of study.

But we are looking at the reliability of the horizontal accuracy versus vertical accurcy. We are also taking into consideration the type of navigational system that was used in evaluating the data. You know, dead reckoning versus satellite navigation. Obviously we are going to go with the satellite in most cases.

We are also looking at the geographic area of the data. In some areas in extreme north and southern hemispheres we know that, given the geographic location in addition to the navigational system, our reliability is questioned. And it's primarily through experience.

Now, as Jim told you earlier, when he gets the information it is about ready for the system. The analysts have given the data very good scrutiny, they have evaluated. They have primarily given this a priority and say, okay, this goes into the system and give it this evaluation. A one is best, four is least desirable, and normally a zero or five is that we can't really determine the evaluation.

A lot of times that occurs in the southern hemisphere, where our evaluation criteria is somewhat lower because we just don't have the saturation of data in that area to do a comparison.

And I think you had one other question and that dealt with --

MR KERR: What do you do with thrown out depths?

MR. LANIER: What was that?

MR. KERR: What do you do with lower order accuracy depths; ones where you have selected a depth point which is, in your opinion, of higher order accuracy than one which is in the same or immediate geographical area?

MR. LANIER: I'm not sure that I really understand your question.

MR. KERR: In one point of latitude and longitude you have two depth values. One you have decided is better than the other one. What do you do with the one you want to reject? Do you keep it somewhere in another file?

MR. LANIER: Yes, we can still store it. We still keep that information available.

I guess sort of a good example of what you're talking about is we may have two different surveys in the same area, from different sources, and some depths are more critical than others. And for our purposes, we are going to go with the shoalest depths because of our navigational responsibilities. But that doesn't mean that we won't use a similar depth on another chart or different scale.

But we are going to definitely go the with the shoalest sounding, or the most critical sounding. And a storage of information, I think, was another one of your questions.

When we store data, our data, as we said, are stored primarily at the Federal Records Center. And we keep the most recent reliable data close at hand, whether they're in the system or we have to keep them in a manual storage container. We still store these data on priority, reliability.

Now, obviously surveys that go back to World War II and have been superseded will more than likely be on microfilm and/or the Federal Records Center.

CDR VANDERMEULEN: Obviously this topic has stirred considerable interest, and I'm sure that Mr. Moran and Lanier are going to be around to answer any further questions that may come up. I am afraid I have to interrupt now, however, to allow our last speaker of this morning's session his reasonable share of time to present his paper.

THE COOPERATIVE TOPOGRAPHIC BATHYMETRIC MAPPING PROGRAM AT THE NATIONAL OCEAN SURVEY

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ABSTRACT

The National Ocean Survey (NOS) has entered into a joint mapping program with the U.S. Geological Survey, The Bureau of Land Management, and State agencies. This program was undertaken to produce maps depicting the topographic and hydrographic details of the coast of the United States and the Great Lakes. This paper presents the techniques employed by NOS to produce these manuscripts depicting the hydrography, shoreline, and nearshore features. The difficulties involved in this type of program are outlined. The efforts of the other Federal and State agencies in this program are also discussed. The various uses of these maps are presented as end product of the use of hydrography.

THE COOPERATIVE TOPOGRAPHIC/BATHYMETRIC MAPPING PROGRAM AT THE NATIONAL OCEAN SURVEY

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Introduction

The passage of the Coastal Zone Management Act in 1972 prompted the National Ocean Survey (NOS) and the United States Geological Survey (USGS) to combine their mapping skills to jointly produce a new, and unique series of maps that would better serve the coastal map user. This series was developed by combining the NOS bathymetry with the USGS coastal topographic maps, and was named the topographic/bathymetric (topo/bathy) map series. The purpose of this mapping effort is to provide the user with a complete picture of the coastal areas' physical environment on a single map. In addition to the bathymetry, the seaward features include mean high water (MHW) and mean low water (MLW) lines, rocks, reefs, ledges, platforms, pipelines, dredged channels, fixed navigation lights, and spoil area. Also depicted on these maps are the Outer Continental Shelf (OCS) lease block information required by the Bureau of Land Management (BLM).

Over the next ten years it is planned to cover the entire coastal zone of the United States with topo/bathy maps, with the contiguous United States being covered by 1:24,000, 1:100,000, and 1:250,000 scale maps. Present plans for Alaska call for only 1:250,000 scale topo/bathy maps to be produced. However, with both USGS and NOS holding a wealth of Alaskan data, and the overall awareness of these northern coastal areas, the Alaskan topo/bathy program may well include a greater variety of scales in the future.

These three scales of maps are the mainstay of the topo/bathy mapping program. By including bathymetric and seaward features on these topographic maps, a more complete representation has been created to aid specific map users involved with this dynamic, resource rich, and fragile area, the coastal zone.

Historical Background

During the 1970's there developed a general awareness of the expanding importance of the coastal areas. At the same time the public was becoming more conscious of the delicate, natural environment of this unique area where land and sea meet. Officials of the NOS and USGS recognized the need

for maps of the coastal areas which would depict a complete representation of the land and water to serve a seemingly endless array of interests, sciences, and disciplines.

Traditionally, NOS has been responsible for the charting of the coastal areas from the shoreline seaward. NOS has produced a series of nautical charts intended primarily for navigational purposes in the coastal waters of the United States. Onshore features depicted on nautical charts are generally limited to landmarks and major features for navigational and orientation purposes. In the mid-1960's, NOS began producing bathymetric maps at a scale of 1:250,000, and other scales. NOS and its predecessor, the U. S. Coast and Geodetic Survey, have, over the years, accumulated a wealth of data in support of the nautical charting and mapping programs. NOS holds a large number of systematic hydrographic surveys and extensive coverage of shoreline and nearshore features depicted on topographic sheets (T-sheets), compiled from tide coordinated aerial photography. This NOS hydrographic and shoreline data would be a major asset to a new coastal mapping program.

The USGS has long produced the standard 1:24,000 topographic quadrangle series and the 1:250,000 series. During the early 1970's the USGS was well into the process of producing a new 1:100,000 series as an intermediate scale between the large scale 1:24,000 series, and the small-scale 1:250,000 series. Using this new base map, the 1:100,000 scale topo/bathy maps series was created.

During the early 1970's, officials of the USGS and NOS studied the feasibility of combining the NOS data with the USGS topographic bases. The result of this research effort was the production of two experimental topo/bathy maps. The first one was a 1:250,000 scale quadrangle of Beaufort, N.C., published in 1972, and the second was a 1:24,000 scale quadrangle of Fort Pierce, Fla., published in 1975. The response to these experimental efforts was generally favorable. The combining of the NOS data with the USGS topographic base proved to be practical, and map users favored the new topo/bathy maps. With the first experimental maps a success, the USGS and NOS agreed to a joint Topographic/Bathymetric Mapping Program in 1975.

Cooperative Members Responsibility and Input

The USGS and NOS are tasked with the compilation and production of topo/bathy maps and contribute the bulk of the data for this effort. BLM is a prime user of topo/bathy maps, particularly for their OCS Leasing Program. BLM makes requests for bathymetric work in certain geographic areas, and supplies lease-block data to USGS and NOS which appears on the completed topo/bathy product. BLM also requests bathymetric maps where the map coverage is totally over water surface areas, they are commonly called "all wet" maps. NOS continues to compile "all wet" bathymetric maps on a reimbursable basis for BLM; however, when BLM requires maps covering land and water surfaces, these mapping requirements are incorporated into the topo/bathy program.

The USGS has scheduled production of the various maps to first produce a set of complete 1:250,000 topo/bathy maps. In addition, when certain state agencies request their coastal areas to be mapped, their requests are accommodated based on priorities and the state's willingness to share costs. NOS in some cases shares with the users in directing scheduling priorities. There are various areas where hydrography is somewhat limited, or non-existent. This problem limits the production of topo/bathy maps in these areas. NOS coordinates map production schedules and priorities with BLM and USGS, based on the data on hand and availability of future data.

Methodology

Once topo/bathy map priorities and production schedules are established, the NOS Bathymetric Mapping Group orders non-photographic blueline bases of the appropriate quadrangles from USGS. With receipt of the blueline bases at NOS, the bases are turned over to the Cartographic Revision Section of the Photogrammetry Division. This unit gathers the necessary charts and T-sheet bases which provide the source data for manuscript base preparation. These sources are at various scales, and must be reduced or enlarged to the proper scale to fit the topo/bathy base. This process is currently performed by a private contractor.

Other sources of shoreline and nearshore data may include nautical chart drawings, more recent photography, and NANCI (New Aeronautical and Nautical Chart Investigations) source material. In addition to the organization of the source material needed to compile the map, a "tick sheet" is generated for each map on the Cal Comp 714. The tick interval of the latitude and longitude is determined by the scale of the sheet, for 1:24,000 scale, ticks are shown at ½ minute intervals; for 1:100,000 scale and 1:250,000 scale maps in the contiguous United States, ticks are shown at 2 minute intervals. The Alaskan 1:250,000 scale maps are at 4 minute intervals.

When the source material has been collected and organized, the USGS base and the NOS generated tick sheet are punch registered along with a sheet of .004 mylar which is used as an overlay for general notes. The assigned cartographer then compiles the MHW line and all other required shoreline and offshore features in black ink. The U. S. Coast Guard Light List is used to determine the existence and range of fixed navigational lights so the correct lights can be shown for the scale of the topo/bathy maps. Low water areas are delineated with a dotted line and green tint; spoil areas and man-made channels are delineated with a dashed line and labeled. Upon completion of this initial compilation, the manuscript base is reviewed for content and accuracy. A detailed summary of the source materials used to compile the new base, including dates and scales, are listed on the mylar overlay.

The completed shoreline base, together with the registered ticked grid, is then forwarded to the Bathymetric Mapping Group of the Marine Chart Division for the compilation of the bathymetric data. Initial preparation requires consideration of what hydrographic/bathymetric sources are available. Compilation of the bathymetric contours are made at the scale of the original

survey, to insure maximum depiction of the bottom's topographic detail. The scale of the majority of the hydrographic surveys is larger than the final 1:100,000 and 1:250,000 published map scale.

The bathymetric contour intervals for the three published scales (1:24,000, 1:100,000, 1:250,000) were chosen to best illustrate the bottom characteristics and variable slopes. The 1:24,000 scale sheets are near-shore and reflect the greatest detail, therefore, a 1 meter interval is used with a one-half meter supplemental contour. The 1:100,000 scale maps carry a 2 meter contour interval, with a supplemental 1 meter contour to the 200 meter contour line. The small-scale 1:250,000 maps use a 10 meter contour interval, supplemented by a 2 meter intervening contour to the 200 meter contour line. All map scales carry a 50 meter contour interval from the 200 meter contour line to the maximum depth, and supplemented by a 10 meter contour.

These contour intervals are used for all topo/bathy maps of the Gulf of Mexico, Alaska north of the Aleutian Islands, Great Lakes, and the Atlantic coast south of 42° N latitude. In the areas north of 42° N on the east coast, the west coast, and Alaska south of the Aleutian Islands, the Continental Shelf has a different gradient necessitating a different contour interval. North Atlantic bathymetric maps employ a wider contour interval due to the increased complexity of the bottom terrain. For the 1:24,000 scale maps, the basic 2 meter interval is supplemented with a 1 meter contour. The 1:100,000 scale map has a 10 meter contour interval, with a supplemental 2 meter contour. The 1:250,000 scale sheet has a 10 meter contour interval with a supplemental 5 meter contour interval to the 200 meter contour. The wider contour intervals along the west coast and Alaska south of the Aleutian Islands are necessitated because the Continental Shelf is narrower and steeper.

During the bathymetric compilation, a number of factors required careful analysis to determine the proper bottom configuration. Factors which affect the quality of the hydrographic survey data are: 1) Type of control used; 2) distance of the survey from the source of control; 3) field procedures used; 4) processing procedures used; 5) application of proper correctors; 6) instrumentation used to gather depth information; 7) weather conditions at the time the survey was made; and 8) when surveys were joined, i.e., the age of each survey is taken into consideration. Only through systematic evaluation of all of the above factors can discrepancies be resolved and proper interpretation of the bottom configuration be made.

Topo/bathy maps are a composite of many different scale hydrographic survey sheets. For this reason it is often necessary to prepare four intermediate manuscripts at 1:100,000 scale to produce one 1:250,000 manuscript. These manuscripts, containing all of the information needed on the final manuscript, are photographically reduced and mosaicked onto the 1:250,000 scale map projection. All bathymetric work and shoreline features are reviewed for accuracy and completeness. Discrepancies, junctions, and other adjustments are rectified and then the final manuscript is prepared. The NOS Reproduction Division uses the manuscript to prepare reproduction plates of the bathymetric and shoreline features for the 1:250,000 scale maps.

These plates are reviewed by the NOS Bathymetric Group and sent to USGS. The 1:24,000 scale and 1:100,000 scale bathymetric and shoreline manuscripts are scribed and color separated by USGS.

With the final 1:24,000 and 1:100,000 scale manuscripts reviewed, the majority of the NOS responsibility is complete. The manuscripts are then shipped to USGS for preparation for reproduction and final printing. In addition to the inked blueline base containing the MHW and low water areas, offshore culture and bathymetry, the NOS furnishes USGS reproduction quality plates of the following features as needed: 1) Bathymetric contours (one to three plates); 2) contour values; 3) shoreline culture (spoil areas, channels); 4) marine type; 5) offshore features (platforms, pipelines); and 6) underwater tint plates. Other NOS information supplied is: hydrographic survey information table; hydrographic survey index; and general marginal information.

Once USGS receives these manuscripts and border information, they are registered to the USGS cultural negative. The MHW line is scribed directly from the NOS manuscript to the USGS cultural plate negative. The low water line is delineated in like manner. A peelcoat is prepared for the low water tint plate. The USGS plates are then adjusted to the new NOS shoreline. The bathymetric contours are then scribed, and type is ordered and positioned. Together with any USGS revision to the culture plate, the plates are reviewed and edited as necessary. A copy is sent to NOS for final review. With reviews by both agencies complete, the topo/bathy map is ready for printing.

Areas of Difficulty and Consideration

Unfortunately, the process of producing a topo/bathy map is not as straightforward as described. There are considerable difficulties involved due to the wide variability of scale, limited coverage, and dates of original hydrographic and topographic surveys. The limits of these surveys rarely correspond to the limits of the topo/bathy map. This often necessitates a very careful adjustment of the data at the limits of the survey to ensure a proper tie. Ideally, all of the hydrographic survey sheets that are comprised in the basis of a single topo/bathy map should be of one time period; in reality it is usually a composite of many survey sheets of several time periods. Therefore, the sheets depict bottom surfaces of a particular point in geological time, which causes difficulty joining the contours from one survey to another to form a single topo/bathy map. However, the NOS collection and compilation standards enable hydrographic data adjustment with a great degree of accuracy.

Summary

The topo/bathy map is a composite map depicting both bathymetry and topographic features. Prior to this, the shoreline was a boundary of mapping responsibility, with NOS responsible for nautical charting, including hydrography and USGS responsible for topographic mapping. This situation often requires those map users interested in coastal features to consult several maps for a general knowledge of one geographical area. The topo/bathy map

is an attempt to rectify this problem, to show the greatest degree of detail possible in the coastal zone.

Currently, the project has produced 53 published maps. Topo/bathy coverage should increase rapidly in the near future as the program becomes more commonplace. It is hoped that the Continental United States will be mapped and published at the 1:250,000 map scale by 1985. Due to a vast number of 1:24,000 and 1:100,000 scale sheets needed to completely cover the coastal areas (nearly 2,000 total), considerable time will be required to complete the entire program. The USGS index of National Topographic Maps and/or NOS Bathymetric Maps Catalog #5 indicate which sheets are published in the topo/bathy series.

AUGUST M. TOLZMAN, NOS: That completes the paper. If there are any questions -- yes, sir.

LCDR GREGORY R. BASS, MARINE DATA SYSTEMS PROJECT: You say there are 53 maps now; approximately 4,000 1:24,000 scale maps to be done. How many total, would you say, including the 1:100,000 and 1:250,000?

MR. TOLZMAN: That's a good question, because I really don't know, off-hand, how many 1:250,000 scale maps there are. But whatever that number would be, would be added to the 4,000.

LCDR BASS: Well, it seems like a large number.

MR. TOLZMAN: Well, we are talking about 1:24,000 coverage of the entire coastal area of the United States, plus the 1:100,000 coverage of the same area.

LCDR BASS: Right. I feel that is a very enterprising project. Nautical charts are maintained as often, or published as often, as six months. Are these topo/bathy charts going to be maintined and new editions published after you get these first?

MR. TOLZMAN: It's being discussed. That's the plan. The plan is that from now on all USGS topo quads covering the coastal zone, which whould have water areas on them, will have our bathymetry, NOS bathymetry, on it. This is what we are striving for here with the two agencies together.

LCDR BASS: Right. I was just wondering if you are going to publish one series of charts or are you going to have that series published and maintain them with new editions.

MR. TOLZMAN: I'm not sure. This is not to replace the nautical charts.

LCDR BASS: Right. Okay. I guess that the answer is you are going to do one series of charts and that will be the end of project?

MR. TOLZMAN: This is Jim McNamara. He is a co-author of the paper.

J.C. McNAMARA, PHOTOGRAMMETRY DIVISION: I have worked on this topo/bathy project. No, the USGS Geological Survey and National Ocean Survey will continue to maintain this series on the United States Geological Survey's revision series for their normal 1:24,000's, 1:100,000's, 1:250,000's. It will be about a three to six-year interval, something like that. So it will be much behind our series of charts.

LCDR BASS: Good. I'm glad to hear that it is going to be maintained. To maintain this large number of charts, have you given thought to automating the process?

MR. TOLZMAN: There has been thought to automated processing, yes. The notes that I have, the people I talk to, I think for two reasons listed, one of them being budget restrictions, they do not feel it is practical at this time. It is definitely being thought of, yes.

MR. ADAM J. KERR, CANADIAN HYDROGRAPHIC SERVICE: Sorry to be here again.

All sorts of questions were thrown out by your paper. First of all, I am interested in the fact that the USGS continues to use a scale of 1:24,000. When you go up to 1:250,000 and 1:500,000 for your smaller scales there, you sort of question why aren't you on 1:250,000 but I suppose that's a small point.

One of the most critical areas of interfacing land mapping with marine mapping is the vertical datum that you chose for it there. And it's particularly critical, obviously, when you have got very fine contour intervals. I think you said one or two-meter contour intervals at the 1:24,000 scale. Nautical charts are produced on a low water datum, and all the data collectors on the the low water datum. At least in Canada topographic maps are produced on mean sea level as a datum there, and I wonder how you reconcile that difference.

I wondered if you are familiar with the Japanese coastal zone maps. They make some rather wonderful maps which not only show bathymetry but they show a lot of other features, which then leads me to ask you what about the surficial sediments. Obviously your land maps show all sorts of cultural data, and it sounded as though the water side only showed the bathymetry. And if you are dealing with oil company leases and things, I should think it would be of interest to know what sort of surficial sediments are there.

CDR VANDERMEULEN: We are already running over the period allotted. Perhaps we can leave it at those two questions.

MR. KERR: Okay, I'll get him after.

Will you answer those for me, though?

MR. TOLZMAN: You want to try that, Jim?

MR. McNAMARA: The statement about the datums, there is a statement on the printed map that there is a variability between the two datums.

Of course, when you get into the United States Geological Survey maps, the topographic features are based on North American. Our bathymetric data is based on mean low water on the Atlantic and mean low or lower water on the west coast. And there is a variability between the two datums, and this is just noted. It is not rectified.

CAPT WELSEY V. HULL, NOS: I would like to make a comment on that.

Adam, to answer your question, in regard to the datum used for the topographic features and the datum used for the bathymetric features, first of all, I would

like to request that we drop the term sea level datum, we were speaking of sea level datum of 1929. When all the interest began in the coastal zone, we saw a problem because the user of that information dropped off "29 and said datum is mean sea level, when, in fact, the datum they are speaking of is the National Geodetic Vertical Datum of 1929.

I think it was around 1973, in the National Ocean Survey, we put an article in the Federal Register and officially changed the name of sea level datum of 1929 to the National Geodetic Vertical Datum of 1929. The topographic contours depicted on the Geological Survey quadrangles are based on the geodetic datum. The shoreline and all of the hydrographic and bathymetric features are based on a local tidal datum.

There is a difference. That value varies, depending on your location. And this only gives a problem in one area to the user of that, but if you go to route a hurricane for your splash model and you are using bathymetric information and topographic information, you do have a variable difference between your tidal datum and your geodetic datum. Regardless of where it is shown on the nautical chart or whether it is shown on the topo/bathy series, the water information is your local tidal datums. Your land is geodetic datum.

Now then, one other thing you mentioned, the low water datum. For a point of information, effective November the 28th of 1980 the National Ocean Survey -- again it was published in the Federal Register -- we are changing the epoch, and we have made the recommendation, which we will be implementing as time permits, to changing the sounding datum on the east coast to Mean Lower or Low Water.

The name gulf coast low water datum presently used on the Gulf Coast will be changed to Mean Lower Low Water, and we have the West Coast on Mean Lower Low Water at the present time. This will give us one continuous datum for soundings.

MR. KERR: Mr. Chairman, I want to follow this point through.

The use of these datums is very significant when it comes to the lower, as you well know in this country, because of the continental shelf cases there, the boundary cases. And under the Law of the Sea, the official base line that is used, is that from your nautial charts or is it from these maps that you are making? I only assume that it's still from the nautical charts. Is it?

MR. McNAMARA: Yes, it is.

MR. TOLZMAN: Thank you, and thank you, Captain Hull.

CDR VANDERMEULEN: Vick, I think I am as thirsty as anybody, and we really should adjourn here as soon as possible to get ready for the second session. Save your question for a private session later, perhaps. Mr. Tolzman does have one comment.

MR. TOLZMAN: I would just like to say we do have a number of the published maps with us here. If anybody would like to take a look at them, come up at break time. Thank you all.

CDR SCHAEFER: Before we start on session five this morning. I would like to introduce Rear Admiral Munson, Associate Director, Office of Marine Operations, also president of the Hydrographic Society.

RADM MUNSON: Out on the back table there is information pertaining to the 20th annual Canadian Hydrographic Conference, which this year will be held in Burlington, Ontario, Canada, between April 7 and 9. I highly recommend it to all of you who can attend, and also it does us good to go up and show them we can drink beer just as well as they can.

They also have a sample copy of their excellent publication, the Lighthouse, and there are applications there for you, and I highly recommend that also for all hydrographers and people interested in hydrography. It is very nominal in cost, and I think you will find it well worthwhile and very informative. All of that is on the desk out in, I guess you would say, the back of the room from here.

On to the announcement, just a few words regarding the Hydrographic Society meeting this afternoon. The Society, I think, got its start much the same as this conference did. This conference was an in-house NOS processing conference originally. It has slowly grown through the years to a hydrographic conference and gone out-house, if you will, with representatives from the Corps of Engineers, DMA, Navy, Canada and others.

The Hydrographic Society started predominantly with the Brits, and I think the stimulation was possibly the hydrography that was being executed in the North Sea to develop the oil fields. But it has grown from that and expanded now so that it includes anyone interested in hydrography whatsoever.

And that includes hydrographers, geophysicists, geographers, chart makers, equipment firms, anyone who is interested in hydrography or the products therefrom. It includes people in the oil rig business, the pipe line business. So, really, if any of you do not feel qualified, let me set your qualms at ease, you are. If you are in attendance at this conference, you are certainly welcome into the Hydrographic Society.

In the United States we have established the U.S. Branch. We are the first national branch outside of Great Britain. This was primarily done by Jack Wallace and myself to make it easier for members to join the society. It was an expediency. It got to be a drag to go to a bank and try to get pounds sterling and get it to Great Britain and wait several months to get your reply back and wonder if you had been accepted.

But what we want to do now that we have established the U.S. Branch, is, this afternoon, at 1615, I believe it is, up in one of the rooms adjoining where we had the beer social yesterday, have an ad hoc meeting. This is our first opportunity to get this many members of the Hydrographic Society in one place. We also welcome any potential members or anyone who just wants to come and listen in, the idea being we are a U.S. branch, now where do we go from here. We would like your ideas. Do we help sponsor conferences such as this? Just how do we bring the nucleus on this side of the Atlantic together.

And also if, for no other reason, you come to our meeting, you will be very convenient for the 1700 cocktail party which will be in one of the adjoining rooms. So you will be there, handy, and certainly won't miss the opening. Thank you.

CDR SCHAFER: Thank you, Admiral.

HANDPRINTED SYMBOL RECOGNITION SYSTEM

A Key Element in Automated Cartography

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ABSTRACT

The Pattern Analysis Laboratory (PAL) of the Naval Ocean Research and Development Activity (NORDA) is developing a Handprinted Symbol Recognition (HSR) System to identify, through computer techniques, free-form, unconstrained handwriting. This R&D effort directly supports the Defense Mapping Agency's (DMA) requirements in automated cartography. The feature/signature analysis techniques developed can also be applied to other ocean science information problems; for example, characterization and classification of patterns related to the mesoscale phenomenon in the water column. At present, the reduction of hydrographic survey data to usable chart form extensively involves the generation, editing, review, translation, and merging of vast quantities of handwritten information. One area of particular concern to DMA is in the preparation of depth sounding data, since the smooth sheet manuscript constitutes one of the primary data sources and archival formats. Computer automated scanning and "digitizing" procedures could greatly improve the efficiency and throughput of these largely manual operations. The key element in such an automated system is sufficiently reliable techniques for recognizing the wide variety of unconstrained handprint used in the preparation of bathymetric charts. A modular approach to this free-form handwriting problem has been implemented at the PAL, which has allowed the completion of the portion of the HSR System that identifies the numerals making up the depth soundings on such manuscripts. The recognition performance for this application requires near-zero substitution errors. The basic concepts and structure of the HSR System, its successful application to this "automated digitizing process," and its extension to handprinted alphabetic symbols will be presented.

1. INTRODUCTION

The development of automated cartography depends on many technologies including such items as digital data handling, computer data bases, electronic display and graphic overlays, document scanners, automated symbol recognition and man-machine systems. One of the major aspects of such cartographic systems is the man-machine interfaces that allow cartographers to perform their tasks in an optimal manner, while maintaining the underlying data in computer compatible form. In general terms, this difficult problem involves a conversion of media between graphic/analog displays/storage of traditional "charts" and digital/electronic forms. Such conversion must be easily and rapidly accomplished in both directions. A second important item is the proper partitioning of tasks between the cartographer and his electronic tools. The interface between these two capabilities is technology dependent and therefore always changing. An example of one such area is computer identification of unconstrained (free-form) handwritten symbols that occur on bathymetric, hydrographic and cartographic manuscripts. The Pattern Analysis Laboratory (PAL) of the Naval Ocean Research and Development Activity (NORDA) is currently developing a Handprinted Symbol Recognition (HSR) System to support the Defense Mapping Agency's (DMA) automated procedures for such documents.

DMA has expended considerable efforts to develop the raster scanner technology needed to generate digital image data of their various products. Such procedures create vast quantities of data ($\sim 10^8$ bits per 40" x 60" document). In the image domain of line drawings, various data compression techniques are available; e.g., raster-to-lineal conversion, run-length coding, etc. However, for symbolic information, such as depth soundings,

names, and oceanographic signs, the end product is a binary or computer code, e.g., the ASCII code for the letter or digit. When the data is in this compact form, it can easily be stored in information data banks and can be managed (retrieved, updated, sorted, cross-referenced, etc.) under electronic/computer control.

Such procedures are in contrast to manual methods required when the primary data storage media are analog/graphic sheets. For example, bathymetric smooth sheets are currently digitized using one of two methods; both techniques use a digitizing table and require an operator to place a cursor over each sounding on the graphic manuscript. In one case the operator enters the correct digital representation of the sounding into a keyboard; in the second case he carefully speaks the digits into a voice recognition system. It is estimated that ten years would be required to reduce the current backlog of smooth sheets using these two approaches.

Techniques designed specifically for this realistic and challenging manuscript symbol environment are being developed at the Pattern Analysis Laboratory. The key link in the DMA compression/automated data handling process is high-performance, adaptable pattern recognition methods that adequately operate in the complex cartographic environment. Before discussing this Handprinted Symbol Recognition System, a brief review of the total graphics conversion process and DMA's performance requirements for such a system will be given.

2. AUTOMATED GRAPHIC CONVERSION PROCESS

The assignment of a computer compatible code to the various symbols occurring in the cartographic manuscript input can be divided into the following scanning/recognition processing steps:

1. The handwritten document must be scanned with a suitable optical/digital system to produce a sampled image in raster format.
2. The image must be thresholded and noise must be removed.
3. Individual symbols must be located, isolated, and tagged.
4. The isolated subrasters must be identified, i.e., recognized or classified.
5. The digits or "characters" making up a sounding or word ("name") must be reassembled and associated with the correct (geographic) location on the document.

Steps 1, 2, 3, and 5 are part of the overall document handling and data management problem. Their relationship to the overall hydrographic survey setting is discussed in Brown, 1979. These steps represent a significant part of the overall automated cartographic process; in the current presentation, however, it is assumed that these functions have been performed.

Step 4, the recognition of isolated symbols, consists of two closely interacting elements: preprocessing of the subraster image and symbol identification. It is a truism to say that "excellent" preprocessing of symbols makes the recognition decisions "trivial"; likewise, "excellent" recognizer logic can handle raw symbols with essentially no preprocessing. However, it is convenient to break the overall symbol identification task into these two parts. Preprocessing generally is concerned with raster smoothing and filling, orientation correction, and "thinning" (Blum, 1967). These tasks are important, since they remove irrelevant character variation, simplify the character structure, reduce noise, and perform an initial data compression. The basic result of this preprocessing stage is a "stick-figure image" in which the interclass variations have been accentuated to the extent

possible while reducing intraclass variations. The recognition system itself extracts features of the symbol and executes a decision mechanism based on the values of these features. The feature vector components can be thought of as the answers to questions which the HSR System has been "taught" to ask. The fundamental definition of the features suitable for providing the "eyes" to see unconstrained handprinting from cartographic type media is a major problem in a high-accuracy recognition system, particularly in view of random location, orientation and distortion of such symbols. The features must be sufficiently "rugged" to allow wide variations within classes while separating different symbols.

One of the functions of preprocessing is to place the symbol image in a correct orientation before sending it to the recognition logic. Such an orientation determination, of course, cannot be accomplished completely out of context; for example, "3's" and the small symbol "m rotated 90° clockwise" may be indistinguishable. Thus, the overall orientation process must be divided into two parts. The image symbol location and isolation subsystem working with the whole document and the context of the "word" involved must provide alignment information needed to bring the symbol into an "upright position" within some angular tolerance, $\pm\theta$. The symbol preprocessing function can then examine such an isolated image and, through calculations based on the image's internal geometry, perform any final orientation correction. This two-step process allows the various portions of the overall system to perform those tasks appropriate to the level at which they operate: preprocessing can use precision techniques for orienting the characters provided they are in a certain "cone"; however, isolation cannot perform this function, but can, through the use of context, provide the cone angle needed.

Although an experimental value for θ has not been conclusively determined, it appears to be between 30° and 50° for most symbols.

3. ACCURACY AND EFFICIENCY: A JOINT OPTIMIZATION PROBLEM

The identification classes in question are the alphanumeric handprint of many styles and authorships and other cartographic symbols that occur on DMA products and intermediate "data sheets." The digitizing/scanning process often leaves artifacts in the images, and it is not uncommon to find images which cannot be placed in any of the "conventional classes" anticipated at the time the recognition logic was defined. Such problem images might be fragments of contour lines or symbols, or coalesced lines and/or characters. Because of this wide variety of potential patterns presented to the recognition system, it is necessary to subdivide all possible realistic scanner images into two basic classes: the set of images for which the recognition algorithm has a high level of quality assurance and the set of all other "unknown" symbols. This decision is fundamental to the HSR System design.

The first set is characterized by the fact that elements assigned to one of its subsets must possess certain properties (features) for membership in that particular subset. These properties are selected such that if "human recognizers" were given a list of these property values (descriptions) without seeing the image, they would agree that the image should be assigned to that particular identification subset (Brown, 1979). If an image has a feature vector (description) that does not match one of the "quality assured subsets," then it is assigned to the "unknown" or rejection subset. Thus, the problem is not only one of discriminating "known objects" with a finite set of predetermined labels, but also of assuring that objects so assigned

have a high degree of confidence of being correct, with any other objects being rejected as "unrecognizable."

The accuracy of the assignments of the "known labels" must be on the order of one mistake (substitution) per thousand or less. Simultaneously, the efficiency of the recognition system must also be high; that is, most images should be assigned a "known" label if possible; even distorted or rotated symbols that are easily recognizable if "seen" should not be rejected. High performance levels for both the parameters of accuracy and efficiency are competing requirements. If a symbol is not well-formed and there is a lack of confidence of accurate labeling because of such "low signal-to-noise," it is better to reject the image; however, this may lower the efficiency. Recognizing nearly all patterns, i.e., assigning known labels in the presence of noise and artifacts, entails the risk of misidentifying many characters (false alarms). Thus, this joint optimization problem for realistic data sets imposes stringent requirements on the recognition system. In simple terms, the system must be "smart enough" to recognize that it cannot make a positive identification of the symbol; that is, that some symbols are "unrecognizable."

Acknowledging the competing nature of this optimization problem, DMA has prioritized the requirements of accuracy and efficiency in that order. It is convenient to state the accuracy in terms of substitution errors; however, as will be seen in the discussion of the experimental results, substitution error rates less than one (1) part per thousand (1000) are very difficult to measure for several reasons: the extensiveness of the data sets required to make meaningful statistical conclusions, the precision of the ground truth, and the difficulties humans have in classifying ambiguous symbols. Indeed,

the problem of determining high quality ground truth for vast quantities of data is not trivial.

In the area of handprinted symbol recognition, it is quite common for techniques to achieve 95% to 98% accuracies, particularly if the data input variability is constrained (Suen, 1980). Results for such ideal "OCR data" are not applicable for the problem at hand; DMA has requested near-zero substitution errors (100% accuracy) in the presence of "random events" of their realistic data products with efficiencies in the neighborhood of 95%. By comparison, a typical accuracy level for machine print (very constrained/ regular symbols) is one error per ten thousand and the pages must be clean and well-formatted.

4. HSR GUIDELINES

Several general principles have guided the PAL research and development on the Handprinted Symbol Recognition System. A three-module approach has been a key HSR concept: (1) pre-recognition, (2) potential numeral identification, and (3) final quality assurance (Brown, 1980). The "pre-recognition stage" is designed to separate "all possible nonmeaningful images" from those that the recognizer has a chance of identifying with minimal misclassification. This pre-recognition stage is one of the most difficult steps to implement. This rejection channel must not be so stringent that it flags as unrecognizable those symbols that are basically acceptable to the recognition module; however, it must, to the extent possible, keep "trash" out of the recognizer subsystem that would increase substitution errors. This process is called pre-recognition in the following sense: the features in this module are specifically designed to recognize "trash"; that is, to identify that a legitimate character is not present.

Examples of feature vector components that measure "trash characteristics" are the height (h) and width (w) of the object and their ratio (w/h), the density of points, a measurement of the number of holes or breaks, and the complexity or number of curve segments. Furthermore, since these "trash features" are specifically designed to perform this "garbage collection" function, not all are useful in actually classifying characters.

If an image is not rejected by the "trash filter," it passes to the symbol identification module. This section of the recognition process uses a feature selection/decision tree approach in which the most reliable and "rugged" features (relative to real-world scanner data) have been placed at the top of the tree.* One of the principal tasks in developing a recognition system is the definition of such features (Pavlidis, 1980). It is important to note that, in the long run, the determination of the suitability of a given feature concept is an empirical problem, particularly in view of the complex symbol environment being considered.

Extensive iterative experiments on feature definition and usage have been carried out in parallel with the overall classifier design. It was found

*This is in contrast to the earlier work (e.g., Lybanon, 1978; Dasarathy, 1978; Gronmeyer, 1978) where the best features relative to a theoretical class separation of ideal characters are calculated first. Furthermore, in the past, many recognition systems have been based on theoretical grounds and idealized input data. When such approaches are used for the present problem, an unacceptable drop in accuracy occurs.

that many features used by earlier researchers are particularly sensitive to minor subtleties in sampling, preprocessing, and intraclass variation (Brown, 1980, and Gonzalez, 1980). The most successful features emphasize global properties of the symbol being analyzed:

- Their calculation involves as many image points as possible.
- They organize the symbol information content in terms of the segments which compose it.
- The number of global segments, their relative orientation, and connectivity are rugged features, since they depend on the reasonably stable properties of end points, branch points, and enclosed regions.
- Individual segments are analyzed, in toto, for their general shape; e.g., curved, straight, spiral, etc.
- These features make extensive use of the concepts of rotation independence and the relative angles between various parts of the symbol.

In all the recognition modules, but most importantly in the identification module, a logic tree approach is employed which can operate in an iterative manner with the feature extraction process. Organization of the recognition logic as a binary decision tree provides an effective mechanism for implementing the feature selection and experimental evaluation. Such a structure can also be viewed as a recursive system with a feedback path between the classifier and the feature extractor.

After a symbol has been tentatively identified, more precise questions can be asked to determine if it is indeed the particular symbol in question. This function is performed by the post-recognition or quality assurance module. The distinction between identification and such verification is

primarily one of emphasis. It is a convenient guiding principle, however, and makes possible the implementation of high confidence levels through the use of a final rejection channel for the symbols not meeting the quality assurance standards. By knowing that an image is tentatively a "5," for example, and that it has been separated from all other possible symbols (for example, that it is not a "2" or an "8"), more particular information or symbol specific features can be extracted which will lower the possibility of a misclassification* (substitution error). Thus, the task of this final module is not classification per se, but is one of establishing that the symbol meets a Sufficient Class Membership (SCM) criterion (Brown, 1979).

A set of feature vector components for a character meets this SCM criterion if their specification "guarantees" that the pattern inside the subraster contains the necessary (sufficient set of) shape characteristics to justify, in terms of human recognizer judgments, the assignment to the character class in question. This concept is in contrast to a known-class separation criterion, which requires only that a set of features be defined which will separate various known (specified) classes. This separation-type criterion is based on the assumption of a predefined, finite universe of classes and does not easily handle the large, unknown number of classes represented by trash. The use of an SCM criterion effectively allows an

*Note that the HSR System requirements place a higher cost penalty for substitutions than for lower throughput. Thus, if the confidence level is not sufficiently high, it is better to reject the character as unrecognizable.

expansion of the number of possible classes which the HSR System can handle by lumping the "infinite trash universe" into a single rejection class. It is also a critical element in achieving the very low substitution rates required of the system.

Results of this dual function post-recognition module, along with the other concepts discussed above, will be given after a presentation of the overall HSR System structure and implemention.

5. HSR SYSTEM STRUCTURE

The HSR program is organized around the major modules shown in Figure 1. The input data structure is a thin line (skeletonized) figure (Duda, 1973). The description of such images is a list of (x, y) coordinates for the image points that are "black" in the raster scan line sampling. This black point image format is first converted into segment-oriented lists. This process of increasing the organizational information content by getting the segment structure of the symbol is carried out by the routine GETSEG. Next, the routine APPROX performs two functions: it acts as a filter and as a data compressor. The segment list structure is not basically changed, but a more suitable subset of points approximating the symbol is generated. This routine processes many points on each segment to arrive at a fewer number of selected points to describe the segment. Besides a reduction in total number of points to be processed by the remainder of the recognition system, this image description (IMAGE 2) suppresses (filters out) local variations.

IMAGE 2 is then sent to a Topology Feature generator (TFEATS) which identifies such things as Number of Connected Components, Number of Enclosed Regions, Number of Isolated Points, various types of Branch Points, etc.

The next two (pre) processes prepare the image for geometrical analysis: A spur analyzer is used to identify short segments that are potential spurs and, if necessary, removes them. The ROT module calculates an orientation angle, rotates the image by that amount, and normalizes its size. The resulting output image (IMAGE 3) is now represented in terms of a real number array (analog-like representation, Greanias, 1963). This approach is in contrast to much image processing work where it is common to use integer representations throughout the analysis. A second approximation stage is being investigated for inclusion at this point in the recognition process. This module would generate an analytic curve fit for the appropriate "segments" of the symbol. The "real-number" representation is quite desirable for such an image description. Several orientation algorithms have been studied; at present, it appears that an eigen-axis approach gives the best results in the sense that it places all symbols of a given class into a reasonably standard orientation (Gonzalez, 1977).

The GFEATS module analyzes each segment and their interrelationships, and calculates geometric features for use in conjunction with the topologic features in the logic tree decision mechanism. The basic three-module approach described above uses this information to arrive at a symbol label for the image.

6. CURRENT HSR IMPLEMENTATION

At the present time the feature extraction/decision logic integration indicated in Section 4 has been only partially implemented. The reasons for this are partly historical, partly for research ease, and partly related to logistics and software development. Until now, it has been convenient to calculate most of the features before entering the logic decision mechanism;

however, there is nothing inherent in the overall HSR design which requires this separation. In fact, as the symbol analysis has become more complex, the interaction between these two major aspects of the recognition process has become inevitable. Thus, the feature extractor needs the information (results of) the decision mechanism in order to know which feature to calculate next, since all features are not meaningful for all symbols. Conversely, not all features are needed in the identification/ verification of any given symbol.

A powerful language system has been developed to implement this integration; it is called PAL TREE for Pattern Analysis Language Tree. This collection of FORTRAN subroutines is an interpreter specifically designed to make it very easy to develop and modify binary decision tree structures concerning arbitrary feature systems. A detailed discussion of PAL TREE (Brown, 1981) involves computer science concepts of virtual processors, language structures, code syntax, etc., and is out of place here. In general terms, each program line in the interpreter describes an "operation" or "decision" and automatically points to the next program line depending on the outcome of the process. The top-level flow chart of a pattern analysis scheme can easily be placed in a one-to-one correspondence with the PAL TREE program lines. What "operations" or "decisions" are executed is contained in "micro code" subroutine libraries and can be tailored to meet the requirements for a specific problem.

With the use of the PAL TREE language system, the researcher/designer can concentrate his attention on algorithms, features, decision structures, etc., quickly convert his ideas into executable form, and carry out recognition experiments to gather statistics concerning the effectiveness of these

concepts. As noted above, the development of a very high performance recognition system is strongly dependent on the empirical/statistical nature of the input data stream. PAL TREE allows such studies to be easily made many times, with variations in the logic/feature structure over thousands of characters in the data base.

7. EXPERIMENTAL RESULTS

This section discusses the HSR test program. Before summarizing the results, however, three factors concerning such experiments will be considered: (1) the context or types of data sets required, (2) the statistical nature of the problem, and (3) various measurement problems.

Any pattern recognition procedure must be evaluated relative to particular types of input data. A major aspect of the design problem for the HSR System is to develop techniques that operate satisfactorily over a wide collection of handprinted symbol environments (authorship, style, and format). The current HSR System has been designed to be extendable to process many symbol sets in the future and also to solve the immediate problem of numeric symbols on bathymetric smooth sheet manuscripts. This type of cartographic environment is indeed a very challenging subset of the more general set of alphanumeric, free-form handprinting. Even within this restricted set, the problems of intraclass variations, orientation and location, and signal-to-noise present a complex environment/testbed for the evaluation of the HSR System concepts. Also, the type or equivalency of scanners employed, the resolution of sampling, and the preprocessing problems involved appear to be essentially the same for the bathymetric case as for the more general handprint problem. In fact, the wide variations in format

(size, rotation, position, spacing, etc.) associated with smooth sheets is certainly greater than for many types of "regularized" documents.

Some preliminary results have been obtained for an alphabetic environment. In particular, one would expect a 100% rejection rate for an HSR System with the only quality assured classes being numerals if it is applied to a data set containing only alphabetic symbols. HSR performance was measured on one such set with excellent results except for such anticipated problem areas as distinguishing between "5's" and "S's", "zero's" and "O's", etc. These experiments have laid the groundwork for a combined alphanumeric system and have provided one illustration of the basic soundness of the quality assurance/rejection channel approach.

The numeric symbol data sets have come from two scanner sources: The PAL video digitizer and the DMA Color Raster Scanner. The source graphics are bathymetric smooth sheets with black ink on mylar. The numerals have a size range of approximately 3:1, with 0.06-0.08 inch typical. The line width also varies with a greater range and different effects. At one extreme, the lines become so thick that enclosed regions are filled in; at the other extreme, lines become so thin that they are "broken or disconnected" by the digital sampling. The sample size can typically be varied from 0.001 inches to 0.004 inches during scanner setup. The smooth sheets used in the tests described below were sampled at 0.002 inches. Line widths in the raster image before skeletonizing are typically 8 to 10 sample points across.

The resolution guideline that has been used to date is that each sample should represent approximately 2-3% of the overall size of the symbol. One should note that there is an interdependence between the maximum sample size permissible and the feature/decision mechanism under development. Therefore,

at this stage of the research it is impractical to perform decisive measures on this resolution parameter. The above guideline appears to provide sufficient resolution to capture the geometric detail needed to distinguish interclass versus intraclass shape variations.

The second major point to consider concerning evaluation is the statistical nature of the problem. Since the symbols being presented to the recognition system are free-form and unconstrained, a wide variety of input images can occur which human recognizers would assign to the same symbol class. This statement considers shape, skew, and style variations within a given classification subset and not the variations of types assigned a "given symbol label." For example, "fours with an enclosed triangle" are in a different classification subset from "open-top fours," which are also given the same symbol label; these "fours" are in contrast to the symbol shapes , , and which constitute intraclass variation within the same symbol label set. Such geometric possibilities, combined with orientation and size (resolution) variations, require that test sets for the recognition system contain sufficient examples of the various classification sets as well as examples of symbols which should be rejected. Simple histograms and multidimensional plots are used to measure the variability of particular features. Large numbers of symbols are necessary to obtain such information required to set the various threshold parameters related to the decisions made concerning these features.

Another factor affecting the size of the data sets is the need to measure the overall accuracies of the HSR System. It is necessary to remember that the accuracy requirements specify substitution errors less than one part per

thousand. This requirement also dictates very large data sets of well-distributed symbols.

The current data base of numeric symbols contains approximately twenty thousand records (symbols) organized in about ten files. This size is marginally small; plans call for additional data to be acquired during the year. Tests using this data base, however, have allowed definition of the remaining problem areas and verification of the current design concepts.

A third aspect of the overall evaluation problem is related to measurement difficulties associated with the ground truth of the data sets. To be useful, each symbol must be "viewed" by a human and a "known label" or ground truth (GT) assigned to it. A dual attribute GT system has been developed; the first parameter is the symbol label and the second qualifier records qualitative information about the symbol such as rotation, distortion, broken, presence of a spur, etc. The experiments thus far have indicated that, in general, the HSR System makes fewer mistakes than the human ground truthers; that is, many errors in ground truth have been discovered as an apparent substitution error. When the symbol was re-examined to determine the cause of the "substitution," it was found that HSR properly labeled the symbol and that the ground truth was in error.

Another question related to ground truth is at what stage it should be generated: (1) the raw raster image; (2) the preprocessed, isolated, smoothed, filled, oriented image; or (3) the skeleton figure input to the recognition system. In the PAL facility, ground truth has been generated at both levels (2) and (3). Usually the statistics experiments use the stick-figure ground truth (3), since that image symbol is actually the object being

identified. In problem areas, however, a reference is sometimes made to level (2) ground truth; for example, in the case of filled-in "6's."

This distinction in ground truth level is also related to a third GT problem area of major significance. Many of the symbols involved in rejections or substitutions are either very badly distorted numerals or "trash" which looks almost like a number. There is a lack of hard specifications for each number through which such ambiguities can be resolved. In fact, different individuals (ground truthers) may disagree about whether a given symbol is a particular numeral or is "trash;" that is, whether it has enough characteristics to be given that particular ground truth label. Such decisions are also related to the penalty paid for mistakes or, conversely, the desired confidence levels. This ambiguity in human judgment is essentially the same problem that the HSR System has in its quality assurance module. In some cases, the stick-figure is sufficiently ambiguous that the preprocessed raster must be considered and even then the ambiguity may not be resolvable. One must note, however, that the current HSR System makes decisions on information contained only in the stick-figure image. An extension of the HSR System to use the information obtained from the external/internal contour of the symbol is currently under development.

Various conclusions can be drawn from the experiments conducted so far. In general, as mentioned above, the HSR System is basically performing better than human recognizers in identifying symbols out of context. The tests have indicated that if the HSR System labels a particular symbol as a given number, then one is justified in having a very high confidence that the label is correct. Furthermore, these experiments have confirmed the

appropriateness of the three-module approach to the HSR System design for this very high performance recognition problem.

In past work a confusion matrix has been used to present the statistical results of a test. Such a matrix has rows labeled by ground truth and columns labeled by the recognition result. The entries in each row and column position are the total number of symbols described by those two parameters occurring in that particular experiment. Confusion matrices for the HSR System as applied to numerals typically have eleven rows and columns: the labels 0-9 and the rejections (R). With the current HSR System, however, such matrices are very sparse; that is, they have very few elements off the main diagonal (equality of GT and HSR label). Furthermore, there is no predominant "confusion" pattern that emerges as a result of such a matrix presentation. Most substitutions are random occurences of "trash" (a ground truth rejection) being misrecognized as a number. For some smooth sheets there is a reasonable number of elements in the last column (GT numerals that have been rejected by the recognition system). Again, this fact emphasizes the importance of an investigation of rejections in contrast to a "confusion analysis". In all cases, however, there are very few elements in the body of the matrix indicating substitutions (less than one element per thousand symbols).

One can conclude several things from these experiments:

(1) the accuracy goal of near-zero substitutions is being achieved and is not significantly affected by the particular manuscript.

(2) the efficiency rate is dependent on the quality of handprinting on the particular manuscript in question.

(3) Examining the rejections in the last column, one finds that most of these numerals are rejected because they do not fit into any of the classes for which the quality assurance module was designed; that is, they do not possess feature vectors meeting the Sufficient Class Membership requirements anticipated when the classes (forms) of symbols were specified.

(4) the efficiences (rejections) range from above 95% on "clean" manuscripts to as low as 60% on very difficult ("dirty") smooth sheets containing poorly formed symbols at random orientations.

The major thrust of the R&D effort in the near future will be aimed at expanding the quality assured classes and thereby extending the range of symbols over which the HSR System can operate satisfactorily. A secondary effort will focus on additional investigations of the interaction between the preprocessing and identification portions of the overall recognition problem.

8. CONCLUSIONS

In summary, one can note that the automated cartographic pattern recognition problem for DMA is similar in several respects to other science information extraction problems in that the input data can have an apparently random structure. In addition to different authorship and styles, manuscripts often have symbols at arbitrary positions and orientations with images outside the known "vocabulary" (class membership criteria). Such conditions are similar to identification of patterns or change detection of manmade objects in other imagery (e.g., remote sensing, side-scan sonar, and magnetometry). The solution to the handprint recognition problem will make an important contribution to DMA's automated cartography and will establish significant techniques for use in other man-machine interactive areas of information extraction and processing.

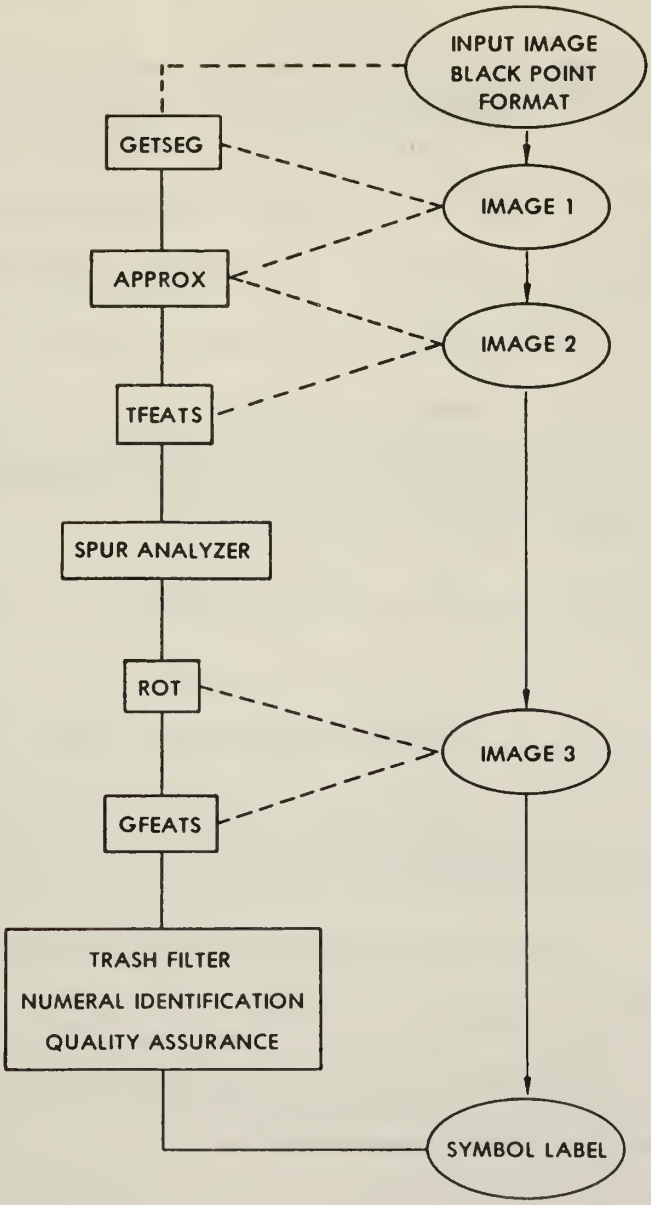

Figure 1. HSR System Processing Sequence

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ROBERT M. BROWN

BIOGRAPHICAL SKETCH

Robert M. Brown is the Principal Scientist for the Pattern Analysis Laboratory at the Naval Ocean Research and Development Activity (NORDA). He specializes in advanced systems research and development in the area of image processing, high-speed computer architecture and time-critical electronic systems, man-machine interaction, and mathematical/simulation models. Prior to joining NORDA, he was the Head of the Advanced Technology Office of the Computer Sciences Corporation (CSC) at the NASA/National Space Technology Laboratories, NSTL Station, Mississippi, where he conducted similar research programs. From 1967 to 1970 he was an Assistant Professor of Physics at the University of Alabama in Huntsville, where he performed studies on hybrid computer teaching techniques. Dr. Brown received both his B.S. in Mathematics and his Ph.D. in Physics from Vanderbilt University. He is a Woodrow Wilson Fellow and has been a NASA/ASEE Faculty Fellow. He was elected to Phi Beta Kappa and Sigma Xi honorary scholastic and research societies and is a member of the American Society of Photogrammetry, the IEEE Computer Society, the IEEE Pattern Analysis and Machine Intelligence, and the Engineering in Medicine and Biology Groups. He is currently the president elect of the Gulf Coast Chapter of the Scientific Research Society, Sigma Xi.

DISCUSSION

CDR SCHAEFER: Are there any questions that you wish to ask at this time?

DR. BROWN: The subtitle I put on this paper is one of the key elements in cartography. The ability to go back and forth between the analog graphic media, that is media that the cartographer is best at making his decisions and compositing charts -- and I am not real sure what all cartographers do, but the person that actually has to bring the information together has gone through a considerable experience in the perfecting tools that allow him to make good decisions.

The problem is when you have huge amounts of information, the best tools for handling those are automated tools; computers, electronics, TV cameras and so on. And the real problem of which this is an example is trying to bridge the gap between those two very fine tools and the man-machine world.

CDR SCHAEFER: Thank you.

BUBBLEBOX - A Reliable Data Recorder for Hydrographic Surveys

by

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ABSTRACT

In the past, the Canadian Hydrographic Service has experienced difficulties recording hydrographic field data on a conventional magnetic tape medium. A solid state recorder, using bubble memory technology, has been developed to overcome the traditional problems of equipment dependability and data integrity. In conjunction with the NAVBOX, which is a microprocessor based data acquistion and navigation system, the BUBBLEBOX will provide an attractive automated logging package that is small, light weight, reliable and easy to use.

INTRODUCTION

The Canadian Hydrographic Service began to consider methods of automating field surveys back in the mid-1960's. From the very beginning, the problem of reliably recording hydrographic data has plagued us. Punched paper tape was used for a relatively short period, but was quickly replaced

Figure 1 - Earlier Magnetic Tape Drive

because of its inherent inadequacies, such as slow speed and frequent mechanical punch and reader breakdowns. The earlier magnetic tape drives (see Figure 1) that replaced paper tape required high power and data integrity was suspect. Because the equipment was heavy, a small launch system was out of the question. Auxiliary generators and the extra payload could only be handled by larger survey vessels. Almost any piece of equipment seemed to work on a ship, as long as a technician and enough spares were available.

Tape cartridges (see Figure 2) were first used as a recording medium on 1974 field surveys. Even though the tape transport performed read after write checks to improve data integrity, the hydrographer could never be

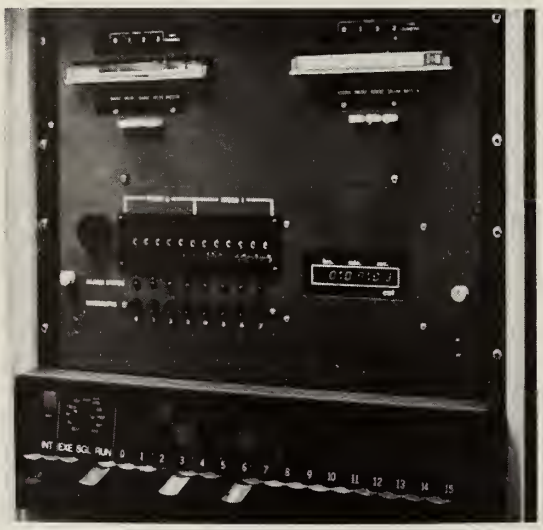

Figure 2 - Cartridge Tape Transport

sure that a tape recorded on board the survey vessel could be read by the data processing unit. The harsh working environment, including extensive vibration, temperature extremes and humidity, was at least partly to blame.

In 1977 the Canadian Hydrographic Service developed a data acquisition and navigation system based on iSBC 80/10 micro-computer products. The NAV-BOX was used successfully under harsh field conditions, from tracked vehicles and helicopters in the Arctic, to small survey vessels on the Great Lakes. (See Figure 3)

Figure 3 - NAVBOX Used in Tracked Vehicles in the Arctic

The success of this system under adverse environmental conditions led to the commercial manufacture of the product, under the name HYNAV, by a Canadian company.

The success of NAVBOX (see Figure 4) also convinced us of two things. One, without a data logger it did not live up to its potential. Two, the environmental impact on field equipment could be practically eliminated by adopting solid state technology, such as that used in the NAVBOX.

Figure 4 - The NAVBOX

The NAVBOX is a portable, 24 DC volt system, ideal for use in small survey vessels. A data logger, to work alongside the NAVBOX, would also need to be portable and work off of 24 DC volts. In 1978 a cartridge drive unit was designed, (see Figure 5) and two prototypes built, to meet these specifications. It proved unreliable under the extreme field conditions to which it was subjected.

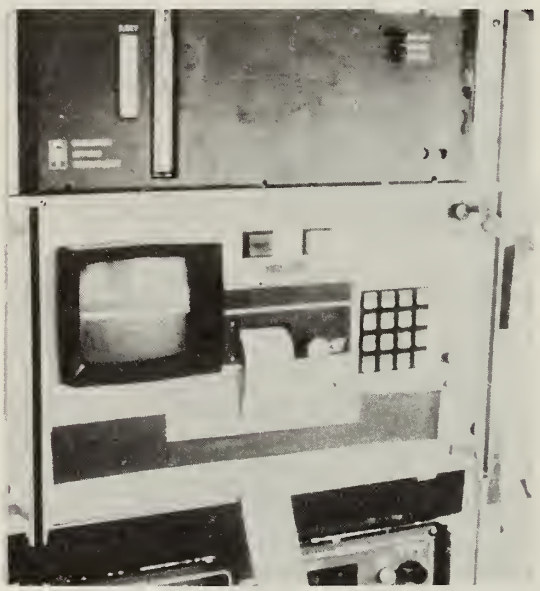

Figure 5 - NAVBOX and Prototype Cartridge Drive

In 1980, magnetic bubble technology had progressed to the point where we felt it was eminently suited to our application. The advantages of a high recording density, non-volatility and solid state technology can be put to excellent use in our harsh operating environment.

With this in mind, a Request for Proposal was distributed to over fifty Canadian companies. Twelve proposals were received, and in August a contract was let to develop, construct and supply two prototype micro-processor based hydrographic data storage units, to be used with NAVBOX units on board small survey vessels.

DESIGN CRITERIA

The success of NAVBOX, due to its small size, low power requirement, versatility and solid state reliability encouraged the Canadian Hydrographic Service to look for similar attributes in the data logger proposals. To the NAVBOX it has to look like a tape drive so that it could be interchangeable with other recording devices that may be developed, without requiring any NAVBOX software or hardware modifications.

The magnetic bubble storage unit must have two modes of operation. It will be used as a logger on board the survey vessel, and as a playback unit to input recorded data to the processing system. Recorded data will consist of two position components and one depth component for each second. Over the period of an operational day a large quantity of data will be stored along with time and administrative data. One mega-byte of bubble memory storage will hold thirty-three hours of survey data.

MAGNETIC BUBBLE MEMORY CHIP

In 1967, research at Bell Telephone Laboratories showed that bits of data could be stored on thin magnetic films. If this thin film is sandwiched between two permanent bias magnets, then cylindrical magnetic domains called magnetic bubbles can be formed in the film when a magnetic field is applied perpendicularly to the surface of the film. A rotating magnetic field is used to move the bubbles through the film, with the presence of a magnetic

Figure 6 - INTEL 7110 Magnetic Bubble Memory Chip

bubble representing a '1' and the absence a '0'. The bubble memory chip (see Figure 6) is a non-volatile storage medium that maintains the high reliability of solid state devices. There are no moving parts to wear out, and it requires little or no regular maintenance.

HARDWARE CONFIGURATION

The BUBBLEBOX will operate as a stand-alone unit (see Figure 7). An iSBC 80/30 will control communications with terminals, data acquisition systems and processing systems. A cardcage/backplane combination, similar to the one used in NAVBOX, will be used. Two fans will draw air from outside the unit to cool the electronic components.

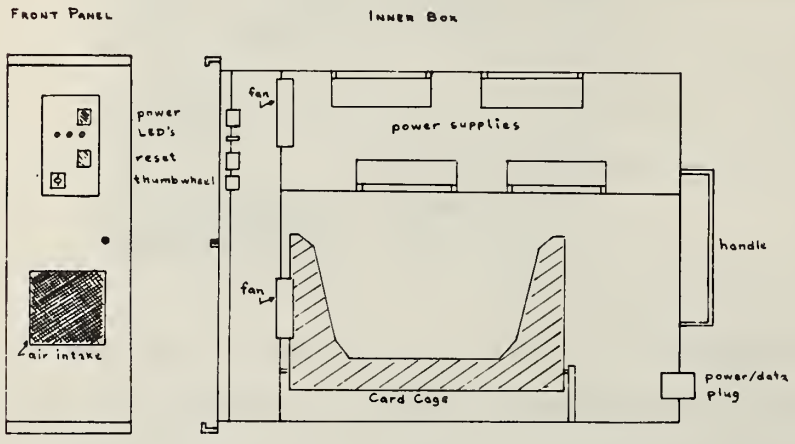

Figure 7 - The BUBBLEBOX

As well as working from a 24 DC volt power supply on the survey vessel, the unit will have a 115 AC volt capability for use with the data processor. The AC power supply will be delivered as a separate unit.

The front panel will have a power switch with an integral breaker and power-on indicator. A thumbwheel switch will select record, playback and test modes, with the full command structure available in each mode. Three LED indicators will show on-line, write mode and error when the appropriate conditions occur.

The unit will be a standard 19 inch rack-mountable box. It will be splash-proof to protect internal components from the environment. To facilitate transportation between the survey vessel and the data processor each day, the BUBBLEBOX will incorporate a 'box within a box' concept. The internal box, which holds the entire unit, can be slipped in and out of the rack mounted enclosure and is held in place by quick-release fasteners.

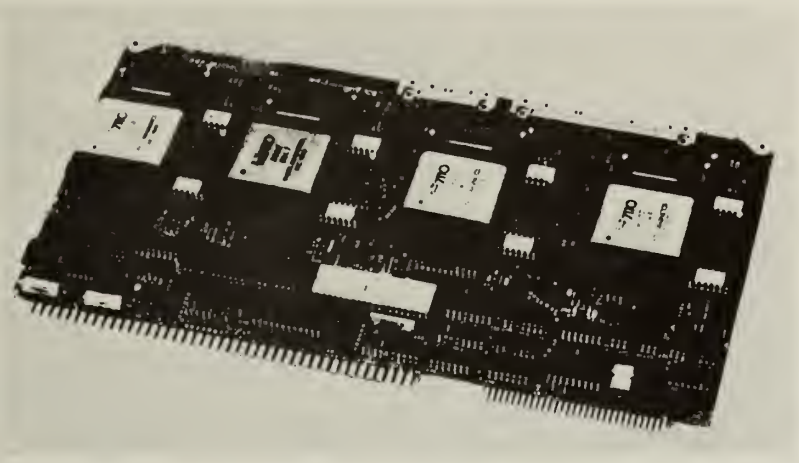

Figure 8 - iSBC Model 254 Multibus Bubble Board

Data will be recorded on two iSBC 254 multibus magnetic bubble memory boards (see Figure 8). Each board incorporates four INTEL magnetic bubble memory chips, each with a mega-bit of memory.

Communications to and from the unit will be via a standard EIA RS232-C serial data interface.

SOFTWARE REQUIREMENTS

The communications protocol will include command and status word definitions to be used by the data acquisition system and the processing system. The functions to be supported by software include write protect, write enable, write a record, read a record, end of record, end of file, rewind, backspace, forward space, send status and execute.

Because of the high cost of data collection in the field, the BUBBLEBOX unit will have reliable powerfail-restart data integrity protection. This will be built into the system through software combinations of maintaining flags and storing status information in bubble memory.

Test software will be used as a diagnostic tool. The BUBBLEBOX will be connected to a data terminal which will respond with a menu of test programs that can be run to troubleshoot a failed unit or otherwise evaluate the quality of a unit.

The program will reside in EPROM. On power up a parity test on EPROM contents will verify program integrity.

CONCLUSION

Two prototype BUBBLEBOX units are scheduled to be delivered by the end of March, 1981. The units will be field tested during the 1981 field season. We expect to overcome the problems encountered with more conventional recording mediums in terms of equipment reliability and data integrity, but we will have to pay the price for quality. The contract calls for an expenditure of over $110,000, with parts for one unit alone costing about $35,000 (prices are quoted in Canadian funds). The greatest percentage of the cost per unit is for the iSBC 254 magnetic bubble memory boards, two in each prototype, at $13,000 each. The price of each unit could be reduced by eliminating one of the boards from the design, reducing the data storage capacity by one-half, but still providing the capability of recording over sixteen hours of data. This would probably satisfy most of our survey applications but, in the prototype, the second board offers a desirable redundancy. The price of bubble memory hardware is expected to drop dramatically as the technology becomes more widely accepted.

By the end of 1981 we hope that the NAVBOX-BUBBLEBOX combination will provide an attractive package consisting of a data acquisition and navigation system and a data logger, that is small, lightweight and reliable, that has a low power requirement and that is easy to use.

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DISCUSSION

ROBERT MARSHALL, CANADIAN HYDROGRAPHIC SERVICE: I'll be glad to answer any questions, and if I can't, some of our people from Burlington may be able to help in the answers.

MR. TOM STEPKA, NOS: You mentioned a figure of 16 hours of survey time for each bubble board; is that right?

MR. MARSHALL: That's right.

MR. STEPKA: How many soundings does that correspond to?

MR. MARSHALL: Oh, one sounding per second.

MR. STEPKA: One sounding per second?

MR. MARSHALL: Yes. Plus the two position numbers.

MR. STEPKA: Plus two line of position?

MR. MARSHALL: That's right.

MR STEPKA: Once you have the data on the bubble board, how is it transported to your data processing computer? Is the bubble board, can it be transported like a tape cartridge, for example?

MR. MARSHALL: The philosophy in the Canadian Hydrographic Service is not to process on line. We always post-plot our data. What we would do here is remove the bubble box and take it and plug it right in the computer just like the tape cartridge.

MR. STEPKA: Thank you.

MR. MARSHALL: Thank you.

CDR SCHEFER: Thank you, Mr. Marshall.

AN ALGORITHM FOR LANGUAGE - INDEPENDENT TRANSFER OF HYDROGRAPHIC INFORMATION

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ABSTRACT

A method of communicating hydrographic information is described. Based on DMAHTC Chart No. 1, "U.S.A. Nautical Chart Symbols and Abbreviations," a controlled vocabulary is used to create an algorithm by which information can be communicated in a language-independent, computer-compatible mode. Using a specific nautical chart and this coding algorithm as parameters, information, such as presented in Notice to Mariners, can be shared by all members of the maritime community. This common format would eliminate the restrictions imposed by the multiplicity of languages and chart formats.

Examples of several Notice to Mariners from various nations as well as calculations of information content and redundancy are also presented.

Introduction

Since earliest days, man has tried to exploit the 70 percent of the Earth's surface covered by water. As soon as the first intrepid sailor ventured from the coast of Egypt, Phoenicia, or Mesopotamia, he discovered the need for a scientific study of the oceans, a study which continues to this day. Great strides have been made in collecting, evaluating, and verifying hydrographic information in the intervening centuries, particularly since the Challenger Expedition in 1876. It is now within the realm of technical possibility to sound any depth and determine any position with excellent accuracy, and to reshape the shoreline, and even to harness the currents.

Of essence in the advancement of all science, including hydrography, is the communication of information. Assume for a moment that the Vikings did, in fact, visit North America in the late 10th or early 11th century. A momentous discovery to be sure, but one which, in the absence of any clear proof, will always be qualified. Leif Ericsson, reportedly visited Newfoundland, and the Vikings might possibly have reached New England, yet Christopher Columbus gets all the real credit for discovering America. Why? Because his discoveries, even if they were not original, were communicated effectively throughout the known world. Without an effective system of communication any advance in technology or the sciences can spread only very slowly, if at all.

So it is with hydrographic and navigational discoveries. During the 16th and 17th centuries only Spain and Portugal had the information necessary to safely navigate to the Orient and back. Contained in books, much like our present day Sailing Directions, these "rutters", as they were called, were prized more highly than gold. The nation which controlled the routes controlled the trade and subsequently accumulated vast wealth.

Since then a spirit of cooperation has emerged out of a concern for the common welfare of mankind and concern for the lives and property involved in oceanic transit. Hydrographic information is no longer a state secret. Cooperation has allowed all maritime nations to conduct their international trade with a high degree of safety.

At issue is whether communication has kept pace with this expansion. Recent years have seen the advent of instantaneous worldwide communication by satellite. Computers are able to handle communications at speeds unimaginable a few years ago. Micrographics, lasers, and fiber optics all promise advances in the near future. But these technologies are not being fully exploited. Consider the Notice to Mariners, which will be the chief example of this report. At present, each of the various

maritime nations produces a Notice which differs in format and, sometimes, language from all others. Each is printed on paper and distributed by mail. To be of use by another hydrographic activity each must be laboriously translated and evaluated.

What is proposed here is not intended to modify this existing system. Instead it is an attempt to use the Notice to Mariners as an example of how the fundamentals of Information Science can be applied to Hydrography. The merger of these disciplines is shown to provide a theoretical basis from which methods may be developed that will be useful in the communication of hydrographic information both nationally and internationally.

The system is designed to be flexible enough to allow a broad spectrum of the Hydrographic community to participate. The procedures will differ slightly, but information can be reported by a cooperating observer aboard a Naval or merchant ship, a member of a survey team, or an information specialist at a national hydrographic activity.

Information Science

It may be beneficial to briefly review the key elements of Information Science. Information Science is a relatively new discipline combining elements of: Computer Science, Library Science, Classification Theory, and Communication Theory. It attempts to define ways in which information can be defined, communicated, stored, retrieved, and otherwise manipulated.

Information is any fact, code, symbol, statistic, or message which has inherent meaning. Information is not to be confused with data; a data item or datum is, in itself, of little meaning. It must be interpreted and evaluated to be considered information.

An example may be useful to clarify the difference. Assume that you are driving a car as it approaches an intersection. On the right shoulder is an eight-sided roadsign, painted red with white lettering. Data elements are: sign, octagonal, red background, and white lettering; collectively these data are sufficient to convey meaning and are thus said to be information. The information is sufficient to trigger a response to the brain initiating a set of actions which stop the car.

Conversely, consider another example. Data elements are: sign, rectangular, white background, and black lettering. No response is triggered. The sign has no information content per se. It might indicate that the speed limit is X, that the fine for littering is Y, that the highway number is Z or so on. You must read the lettering printed there and interpret it for meaning and relevance to your present needs. If the data on the sign doesn't have meaning for you or if it doesn't reduce uncertainty, no information has been transferred.

Three points which are central to this discussion are suggested by the second roadsign. First, the shape and color of the sign are insufficient to convey meaning. It requires additional data for the sign to be useful. This is an important concept to which we will return. There is in every message a minimum number of symbols which are necessary to convey meaning. The system presented in this report attempts to reduce a hydrographic message to only this essential information.

Second, assume that the printing on the sign was incomprehensible or obliterated. Aside from providing one more distraction, the information the sign was intended to convey has been lost. The sign which told of the bridge around the next blind curve being washed out failed to warn of this danger, and thus the driver is unaware of it. And the next driver, and the next.

Like many early explorers these drivers can't benefit from the experience of others who have preceded them. Each driver has to navigate as well as he can. The sign did not communicate the information so there never really was any information.

Finally, suppose that the sign was clearly legible but in a language you did not understand. It carries no information for you. Even though it carried a sufficient, unambiguous message, it conveys no information to someone who doesn't know the code.

Alternatively, consider our stop sign again. The shape, the color, and the code are each sufficient to convey meaning. A white on red sign signals stop. An octagonal sign signals stop. To an English-speaking driver "stop" signals stop. The message is clear, all white on red signs are stop signs, all octagonal signs are stop signs. Even without the lettering, the sign is a symbol which has a clear meaning __ STOP!

A key point in our discussion of information is that of uncertainty. Information reduces uncertainty, data does not. Information is unambiguous in form and does not introduce a possibility of misunderstanding or misinterpretation. A symbol in a message which carries an ambiguous meaning reduces the information content of the message.

In order to reduce the ambiguity of symbols in our everyday speech we add modifiers. Within the framework of grammar, modifiers reduce uncertainty and ambiguity. For example, it is possible to speak of a rock in terms of hydrography. As a term, "rock" is ambiguous. It requires modifiers to define it more clearly. It could be a rock above water, a rock which dries at certain stages of the tide (which must be specified), a rock awash at a specified datum, or a sunken rock which may or may not be dangerous as defined by depth and position. The modifiers must be present to define the rock.

Each hydrographic feature requires a specific set of modifiers to give it meaning. We have discussed rocks as an example but the same holds true to other features, such as buoys. Buoys can be a variety of shapes, colors or systems (Cardinal, Lateral, IALA, etc.). Depths, whether dragged or sounded, verified, or suspected, can be in fathoms, feet, meters, or shots of anchor chain. A feature has a specific, finite set of modifiers which it must have and no others. The use of modifiers can be said to be precontrolled.

Another fact must be kept in mind. The use of a natural language, i.e., one in actual spoken use such as English, French, Russian, or Japanese, introduces the nuance of grammar and usage to the words of any message. When a sailor gets

ready to "hit the beach" we all know he's not preparing to box with a sand dune, but a word for word translation into Japanese might indicate this.

Nor is English free from ambiguity even in proper usage. Consider the simple declarative sentence: "She told me that she loved me." Now add the all-purpose modifier "only" anywhere in the sentence. In fact, it can be put in any place in the sentence and make sense although all of the possible sentences have slightly different meanings.

To eliminate confusion which can result from the use of a natural language, we may employ an artificially constructed language with a simple grammar which is rigidly adhered to.

Such an artificial language employs a limited or controlled vocabulary; as mentioned earlier this language is precontrolled. The vocabulary in this case consists of a number of words and symbols which should be immediately understandable to anyone in the Hydrographic community.

The grammar is controlled first, by limiting the message to 80 alphanumeric characters, this will allow the message or character-string to be transcribed and stored by computer. The reader may be aware that some computer systems will accept up to 120-character-string messages. Until such time as interactive terminals become widely available, however, an 80 character message should suffice.

The grammar is further controlled by assigning each of the 80 fields to a specific mode (alphabetic, numeric, or blank). Each field can have only certain defined values which will always mean the same thing. The grammar dictates the relative positions of the subject, object and action verbs of the message minimizing the confusion which occurs in natural languages.

Hydrographic Messages

The fundamental unit of this coding algorithm is the hydrographic message. By utilizing a common format, information can be freely communicated and clearly understood by all members of the Hydrographic community. We have examined the theoretical basis for using a controlled vocabulary approach with an artificial grammar, let us now examine in detail the prime elements of the message.

Chart Number-Subject

The first data-group on a message contains seven fields of alphanumeric characters and consists of the chart number. Most nautical chart (National Ocean Survey and Defense Mapping Agency Hydrographic/Topographic Center) numbers are six digits, the seventh field is reserved for use when the reported information falls on a plan or inset. On DMAHTC charts, and on most foreign charts of multiple plans, they are designated by letters A, B, C, etc. Insets or undesignated plans must be indicated by their position on the chart.

The coding rules are as follows:

Fields 1-6 — chart number 2 to 6 digits, left-justified and blank-filled.

Field 7 — plan designator, alphabetic A, B, C etc. or I if a single inset, or T-top, B-bottom, L-left, R-right if multiple undesignated insets.

For several reasons, the nautical chart was chosen as the base upon which all information will be reported. First, because this is the system currently in use for U.S. Notice to Mariners. Second, because this will allow Naval and merchant mariners to cooperate in reporting information. Survey information may also be reported in this manner, either on an existing chart or with a slight modification of the computer programs on the survey sheet.

Action Verb

The assumption is that any change to be made on a chart can be indicated by a single action verb. The verb is coded by a single numeric field giving a total of 10 possible verbs of which five are presently used at DMAHTC.

The coding is as follows:

1. Add
2. Change
3. Delete
4. Relocate
5. Substitute
6. -Ø Have not yet been assigned.

Chart Symbol-Object

The primary premises of this report are that: (1) it is possible to define any chart symbol by a three-symbol alpha-numeric code; and (2) that chart corrections are modifications of the symbols which appear on a chart.

While the latter premise appears self-evident, it is nevertheless necessary. Since we have chosen the chart as the data base, we have reversed the traditional basis of reporting hydrographic information. The usual methodology of reporting utilizes the geographic position as a basis; e.g., the buoy in position N has been moved to position M, or the depth in position X is Y fathoms. This scheme proposes that reported information is best suited to update an existing data base; i.e., a specific nautical chart.

To return to our first premise, the three-symbol codes to be used will be essentially those in Chart No. 1, "Nautical Chart Symbols and Abbreviations." For example, if the reference is to a stranded wreck, the code would be 013. The code references the symbol, not the wreck itself.

In a similar way, any symbol can be coded by the originator of the message and decoded by the recipient. The advantage of the code over plain text is that there can be no question on the part of the recipient as to which of several classes of rocks or which of a score of buoy symbols was intended.

Decoding the message does require that an additional publication be used but this disadvantage is compensated by the increase in accuracy.

An additional, very important advantage of this system is that it is not language-bound. A non-English speaker can easily encode a message.

Position

Transmission of the geographic position is one part of a typical message which cannot be substantially reduced in length. It will require a maximum of 16 symbols to encode a position and this has been allocated.

The coding is as follows:

Latitude degrees (2), minutes (2), seconds (2) decimal (1)

Longitude degrees (3), minutes (2), seconds (2) decimal (1) Quadrant (1).

The quadrant of the globe can be identified by a single digit:

1. North and West
2. North and East
3. South and West
4. South and East
5. cross Greenwich Meridian, West first
6. cross Equator North first
7. -Ø not assigned

Quadrant codes 5 and 6 are intended to be used when more than one position is necessary as in the case of an area, a cable or pipeline or a relocated aid when the positions fall in different quadrants.

Even though there are 16 fields allocated for the position, few occasions allow a determination to be made to this precision. Therefore, an adjustment will be allowed. Using an odd number of digits after the degrees will indicate that the last is a decimal; e.g., 653 is read as 65.3 degrees, 65233 is read as 65 degrees 23.3 minutes.

Position is to be left-justified and blank-filled if any sub-unit is not used. In time the system can be modified to accept variable length positions.

It may appear that describing the position in terms of quadrants is an unnecessary complication to replace two alphabetic characters with one digit. The intention is not to go to extremes to shorten the message, but to eliminate its dependence on language.

North, South, East, and West and their abbreviated forms are so familiar to us that we overlook the fact that they are English words. This coding algorithm has been designed to be, so far as possible, entirely free of any natural language so that it can be used effectively by anyone, whether he

understands English or not. In fact, if a message is properly coded, it will be impossible to tell which language it was encoded from. This should be welcomed by bilingual countries such as Canada and Belgium, multilingual countries such as India, and by other countries such as the Netherlands and Denmark whose languages are in very limited use outside the country.

We shall now briefly examine some of the other elements which are necessary to the message.

Chart nationality (2 numeric)-since we have limited the chart number to 7 digits, it will be necessary to develop a code for the producer of the referenced chart. Up to 100 countries can be accommodated. This list has yet to be developed, but we can use ØØ for DMAHTC and Ø1 for NOS as an example.

Edition (6 numeric)-indicating the edition number (2) year (2) and month (2) of the chart being used.

Last Notice to Mariners (4 numeric)-notice number (2) and year (2) provides an audit trail to insure that all corrections to this chart have been received.

Chart No. 1 used (1 numeric)-rather than impose the use of the U.S. Chart No. 1, it is proposed that a message can be coded from any of 10 lists of chart symbols. If this system is to be accepted, a new chart symbol pamphlet will have to be produced by the participating country. In the interim, a transmitter must use one of the existing charts listed below. To be sure of being able to decode any message, a receiver would need all of these charts. This puts a burden on the receiver, but since only a national hydrographic activity would find it necessary to collect data from all sources, only they could find it necessary to carry a full complement of Chart No. 1s.

The coding is as follows:

1. I.H.O.
2. British Admiralty
3. Canada
4. France
5. Germany, Federal Republic
6. Japan
7. Spain
8. U.S.A.
9. U.S.S.R.
Ø not assigned

This concludes the listing of elements common to all reports. A brief review shows that we have assigned the first fields as follows:

1-7	Chart number
8-9	Nationality of chart producer
10-15	Chart edition
16-19	Last Notice to Mariners
20	Action verb
21	Chart 1 used for encoding
22-25	Chart symbol
26	Quadrant
27-42	Position
43-80	Flags, details, and text.

Flags, details, and text will consume a large portion of some messages and less for others. An in-depth analysis is beyond the scope of this report; additional work has to be done. At the present time, however, we can examine the scope of the problem and identify areas where details must be settled.

First, definitions of the terms are in order. A flag is used here in the data processing sense, certain numbers in certain positions will trigger or flag the computer program to take certain actions. For instance, action verb 4 (Relocate) always indicates that there will be a second geographic position in the message. A chart symbol Q (Soundings) will indicate that the numeric value of the sounding will be included. It is expected that these flags will be written into the computer programs to manipulate the messages. If programs are properly written these flags should be user transparent; that is, the user need not worry about them.

Details are those data which are needed to complete the message such as the second position and the sounding value.

Text is that portion of a message which cannot be coded. The use of quotation marks in the message will indicate that everything within is to be printed as is. Text will include proper names, morse code characteristics or radiobeacons, notes, warnings, and legends not included in the symbol codes. While textual information is, no doubt, important, it will usually be in the language of the chart producer and thus subject to the problems related to natural language.

The following is an overview of details which have been identified. The "If-then" statements should be familiar to any computer programmer and should serve as an example of how the programs can be written.

Action Verbs

If 2 Change, then further details are required
If 4 Relocate, then two positions are required
If 5 Substitute, then two symbols are required

Chart Symbols

If A Coastline, then multiple positions are required
If C Land Features, then multiple positions are required
If D Control point, then elevations may be required
If E Units, then quantity is required
If G Ports and Harbors,
6-11 piers, jetties etc., then two positions are required
12-13, 46, 49-51 areas, then four or more positions are required.
If H Topography, then at least two positions are required
*If K Lights, then K10-13 (position) is required as are characteristic K21-26 and color K61-67.
*If L Buoys, then type 1-33 and color 41-48
If M Radio and Radar Stations, then characteristic signal and frequency are required.
If O Dangers, then depths may be required
If P Various Limits, then multiple positions may be required
If Q Soundings, then values of sounding are required. Unit of Measure will be the same as chart.
If R Depth Contours, then multiple positions are required.

Returning to the coding of the message, starting at the next open field (43), we find our flags as we read from left to right. If the action verb is Relocate, we have identified the chart symbol so we can assign the next 16 fields (43-57) for the second geographic position. In a like manner, if the action verb is Substitute we can assign the next 3 fields (43-45) to the second chart symbol.

Action verbs Add and Delete do not automatically require details; they take their keys from the chart symbol.

The Change verb will usually refer to some existing detail on the chart; e.g., light characteristic, buoy, color, radiobeacon frequency, etc. In this case the reference chart symbol should be the symbol to appear on the chart, and details should begin in field 43.

*If a message refers to a light or buoy, additional coding is required.

Lights and buoys are the primary object of the Change verb and are the features least easily coded from the existing Chart No. 1. The coding algorithm below is proposed as a partial solution to this problem.

Knn indicates a light.

First digit indicates type of light.

1-. any light symbol
2-. light symbol with riprap surrounding
3-. aero light
4-. light beacon
5-. light vessel
6-. light with obscured sector(s)
7-. range or leading light
8-. sector light
9-. leading light

Second digit is unassigned at this time. In the event a suitable second key can be devised, it can be implemented at some point in the future. At present this field equals Ø.

The use of any K symbol is a flag for details in the following order:

(A) Characteristic (n numeric)
(B) Color (1 numeric)
(C) Period, in seconds (2 numeric)
(D) Notes (2 numeric)

Characteristics are coded as follows:

01. F, fixed
02 Fl, flashing
03 OCC, occulting
04-n unassigned

The (A) Characteristic field is of variable length to allow for group characteristics such as group flashing (3 & 2). Characteristic is left-justified on field 42 and terminated by a single blank.

Color is coded as follows:

1. amber or yellow
2. blue
3. green
4. orange
5. red

6. white
7. black
8. Ø not assigned

This color coding is also used with buoys and beacons.

Period in seconds is self-explanatory.

Notes are assorted text such as "Exiting" and "destr" which appear under K in Chart No. 1. They are coded the same as any other chart symbol except that they do not take a K in this position.

Light code K80, sectors, sets a flag for an additional group. Sectors are coded: color code (1 numeric), arc (3 numeric, 000°-360°). Any arc not assigned is assumed to be white.

Obscured sector takes the same form; color code, arc, except that color code, if not otherwise noted, is presumed to be an obscured portion.

If any of these details cannot be determined, this can be indicated by leaving a blank.

If any details cannot be coded from the above tables, they can be included as text, for instance light vessel "Borkum Riff" or "Nantucket."

Buoys present a less challenging but, nevertheless, troublesome problem. There are a number of different symbols in use for each type of buoy. If one symbol can be decided upon, then it will eliminate confusion. At present Chart No. 1 lists symbols for 33 different types of buoys, and the list appears adequate enough to allow coding by this algorithm (Lnn). A buoy does require details, primarily color, but also top-marks and radar reflectors.

As mentioned earlier, buoys can use the same color codes as lights with the exception that two fields must be allotted to allow for the large number of two-color buoys. When, as in the case of a junction or danger buoy, the color of the top band makes a difference, it is given first.

This algorithm is an attempt to formalize all hydrographic messages in a rigid, logical, albeit, somewhat complicated manner. Each code group represents specific information dependent for its meaning on the groups which precede it.

You will note that an area symbol will trigger a flag to require one or more positions in the details section, a depth symbol to require a discrete number and so on. There will be occasions where a message will be longer than 80 characters. In such cases there must be some method of continuing the message. Therefore, we shall introduce the final two codes which are primarily for record-keeping purposes.

Correction number (2 numeric) is to be used primarily by producers of Notice to Mariners, to indicate, for example, that this is the 76th correction to this edition of the Chart. This code is optional, and if used it is preceded by a non-alphanumeric character such as a comma in field 76.

End of character-string (1 numeric) is always used and field 80 is reserved for it. It is coded as follows:

Ø end of message
1 additional

This concludes my discussion of the coding algorithm itself. The balance of my remarks will address implementation.

Implementation

The coding algorithm may seem, from the text, to be quite complicated. In fact, it isn't. It is no more complicated than the scheme in use for U.S. Notice to Mariners and immeasurably less complicated than plain English.

It will, of course, be necessary to prepare a coding guide for users of this system. Anyone who has ever been a weather observer aboard ship, and those from NOS who are familiar with the data collection program for weather, can visualize just such a guide which has been in common use for many years.

NOAA's weather report collection program enlists the assistance of cooperating weather observers on board ships. I can recall filling out coding sheets many times. Even without knowing anything about computers, the guide takes the observer through the report in a logical, step-by-step procedure and allows him to encode a great deal of information on a single line on a coding sheet.

At the same time the coding guide is prepared, the Chart No. 1 can be revised eliminating unnecessary symbols and providing each useful symbol with a discrete number.

Once these tasks are accomplished, a test period can take place. Messages can be coded and decoded by hand and compared. If no information is lost or garbled, then the computer programs can be written.

The computer programs need not be very sophisticated. This algorithm was developed with the computer in mind; nothing should present any difficulties for a working programmer, particularly one who is skilled in writing in COBOL.

Conclusion

The chief value of this system, indeed its only real usefulness, lies in its use as a kind of "lingua franca" for the hydrographic community. A century or more ago all diplomacy in Europe was conducted in French. Similarly, English is the universal language of commercial air transport; a French airliner landing in Istanbul communicates with the tower in English. To communicate hydrographic information effectively, a common language is needed. It is to this need for a common language that this report is addressed; such a common language is possible. Whether it is this algorithm, some variation of it, or a completely different scheme is of little consequence as long as the old parochial communication methods are allowed to become extinct.

A modern communication algorithm will allow hydrographic messages to be transmitted by radio, telephone, or telex. Consider, on the other hand, the delays inherent in the present system. A message, in this case a Notice to Mariners, is laboriously written out, edited, typed, set in type, printed, bundled, mailed, sorted at the receiving end, delivered to the proper office (hopefully), and laboriously translated word by word if not sent to a translator (involving most of the same steps again). Is a month to six weeks sufficiently fast communication for information this vital? I think not!

The world is now entering the Information Age, which many have compared to the Industrial Revolution. This is, perhaps, overstating the fact a bit, but the Hydrographic community must exploit the new information technology.

SDS III--THE REPLACEMENT FOR HYDROPLOT

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ABSTRACT. The NOAA Fleet's Shipboard Data System III (SDS III) in its hydrographic application is seen as the replacement for HYDROPLOT. The objective for this application and functional characteristics of the system are described.

INTRODUCTION

Shipboard Data System III (SDS III) is the next-generation computer data acquisition and processing system of the NOAA Fleet. It will replace the various existing computer data systems with common hardware components and, to whatever extent possible, common software to serve the needs of all users of the NOAA Fleet. Existing systems need to be replaced because of their age and decreasing reliability, and because of the desire to apply new technology to improve field data operations.

In its hydrographic survey application, SDS III is seen as the replacement for HYDROPLOT, the system used by the National Ocean Survey (NOS) hydrographic program for more than 10 years. This hydrographic application also represents the driving influence in establishing the characteristics of SDS III, since it encompasses approximately 80 percent of the Fleet's computer systems inventory and poses the greatest demands in complexity of data operations and in system capacity.

The present conceptual design of SDS III is described in terms of hydrographic survey functions. The description is limited to general features of the system and does not begin to address specific details or the seemingly unlimited facets and nuances of system performance. The design itself did not result as a direct answer to comprehensive and precisely stated hydrographic program requirements, but rather evolved from a continuing process of trade-offs in short- and long-range program objectives, technological possibilities and risks, present and projected field operations conditions, and resource requirements of all sorts. It represents a reasonable balance between vaguely defined requirements and limiting conditions. Since these requirements and conditions continue to change, the design can be expected to change as well.

Certainly, the hydrographic survey program is pursuing two general objectives in SDS III capabilities:

1. Enhancing the efficiency and effectiveness of survey operations by, for example,

- making more extensive use of computer capabilities in repetitive tasks and operations support tasks;
- matching system functions and data handling capacity more closely with survey processes and tasks;
- ensuring system flexibility;
- increasing data collection capacity;
- coupling the system with external data systems that provide digital source data to SDS III and utilize data from SDS III;
- simplifying the system's operation; and
- ensuring adequate performance reliability.

2. Improving data quality and utility through

- incorporating sensors and mathematical routines to correct for systematic and random errors in data;
- systematizing data processing under computer program control; and
- recording all available, pertinent data to permit data selection for various purposes.

OVERALL ASPECTS OF THE SYSTEM

Certain concepts underlie or are incorporated into the overall hydrographic SDS III; a brief discussion of these concepts may serve to clarify the specific descriptions of the data acquisition and processing systems that follow.

The clear distinction made between the data acquisition function and the data processing function is manifested by the functional and hardware differences between the Data Acquisition System (DAS) and the Data Processing System (DPS). The DPS constitutes the center of the overall hydrographic operations within a survey party. It contains the central repository of all machine processable data for the party, embodies the capability for sophisticated data routines, and provides for the orderly and efficient management of data. It supports, and is in turn supported by, one or more DAS that utilize its resources and contribute to the growing volume of survey product data. The DAS thus subserves the DPS, recording and storing data only temporarily. The capacity of the DAS and, therefore, its size, complexity, power consumption, and cost are significantly less than those of the DPS.

The survey sheet will continue to be the end product of hydrographic surveys, depicting in a traditional manner survey data for the geographic area encompassed by the sheet and at the scale of that sheet. The digitally recorded representation of that data will, however, assume priority over the graphic representation. Notwithstanding this orientation of the end product toward sheets, data in SDS III will be stored and managed with orientation toward the survey project in which the party is engaged, where the project represents a defined overall geographic area and a contiguous time period of survey operations. This will divorce operations from the artificial constraints of arbitrary sheet limits. Project data stored in the DPS identify the following types of data.

Historical data include all existing charted matter, prior surveys, junction surveys, and presurvey review items. These data are stored before the beginning of survey operations and will generally not be changed during the survey project. Since they represent copies of data existing elsewhere, they will not be included in final survey products.

Reference data encompass all information, facts, constants, parameters, etc., necessary to execute survey operations and to compute survey product data. They include, for example, the boundaries of the project and the survey sheets, survey sheet scales and other parameters, position control station lists, equipment identification and performance (calibration) data, tide and sound velocity adjustment data, and shoreline data. Reference data can be expected to change and be added to frequently, and most reference data will form an integral part of the documentation of final survey products.

Survey product data comprise all data that are considered the desired product of the survey. They consist for the most part, of depths and symbols with associated geographic positions, some elevations with positions, and descriptive information.

Survey supporting data are the assemblage of basic information from which the survey product data were derived. They include the values of time, lines of position (LOP), soundings, heave, roll, pitch, etc., that were obtained for each data point, as well as necessary references to data contained in the reference data files. Survey supporting data are generally not modified. The volume of these data increases in proportion to the survey product data volume, and they form an integral part of the documentation of final survey products.

Raw hydrographic data are recorded by the DAS and are in a class by themselves. They are oriented to the time sequence of their acquisition rather than geographic location, and exist only from the moment they are acquired until they have been copied and processed in the DPS and have become survey product, survey supporting, or reference data.

A specific mechanism for tracking the instrumentation used in data acquisition will be used to monitor and correct for instrument errors in the data. At the center of the mechanism is the survey party's Master Instrumentation Table (MIT), which is a precise and complete inventory of all instruments in

the party together with their characteristics and parameters that affect their performance, such as the frequency of transmission of phase measuring positioning systems or the calibrated sound velocity of an echo sounding system. The survey vessels are included in this table together with their static and dynamic transducer draft characteristics and geometry of antenna and transducer locations.

Directly associated with the MIT are the Instrument Calibration and Correction Files (ICCF) that embody all available data for the determination of corrections for specified instruments or combinations of instruments of the MIT, such as combinations of mobile and shore instruments of a positioning system. These files will include all results of systematic calibration effort and of the calibration checks conducted during field operations.

To obtain the required instrument correction values, the instruments actually used are identified in the Vessel Instrumentation Table (VIT) for mobile equipment and in the Control Station Table (CST) for fixed equipment. Since instrumentation suites change from time to time, the VIT and CST contain date/time entry arguments. The instrumentation-related tables are contained in the Reference Data group and are referred to in Survey Support Data.

Three elements of the hydrographic data reduction process have been specifically identified as "models," since they are inherently complex and are expected to evolve in increasing sophistication. They are

1. the Systematic Effects Model for positioning systems that incorporate measurement effects of, for example, ground conductivity, radio wave propagation, distance from station, signal strength, and phase cancellation;

2. the Sound Velocity Structure Model that defines the variation of sound velocity in water in time and space; and

3. the Tide Model that describes the variation of the mean water surface level in time and space.

DATA ACQUISITION SYSTEM

The functional hardware configuration of the DAS is depicted in figure 1; technical details of the various components, interfaces, dimensions, installations, etc., are not addressed here.

The heart of the system will be a microcomputer capable of accepting keyboard commands; recording data from various sensor systems on the magnetic tape cartridge; performing required computations; generating CRT displays, text printouts, and plots; and displaying left/right indications for guidance in steering the vessel. No random access digital storage devices are associated with the computer; consequently, all necessary survey programs and data are "memory resident" in the computer. "Real time-of-day" to tag acquire is generated within the DAS computer by battery-operated module that will maintain accurate time over extended periods, independent of the system's main power.

The sensor systems are the principal sources of data to be acquired but are not considered part of the DAS. Flexibility in the hardware interfaces and in DAS software permits various combinations of sensor systems to be attached. Each sensor system can, therefore, be handled individually. Sensor system suites include the customary phase measuring and direct distance measuring positioning systems and echo sounders, as well as heave/roll/pitch sensors, digital compasses, and possible vessel speed measuring devices. Data are also entered via the hydrographer's keyboard and may include descriptive notes or manually entered measurement data.

The hydrographer uses a combination of keyboard and CRT display screen to communicate with the DAS. The CRT screen can continuously display various sets of data; be used to generate descriptive notes for digital recording; prompt the hydrographer for specific actions, information, or data; or convey problem or alarm indications to the hydrographer. The CRT is a common line text display device without sophisticated graphics capability. The printer included in the hydrographer's suite of peripheral devices is not intended to generate any final or retainable data printouts, but may be used to make hard-copy printouts of selected data for use during data acquisition operations.

An automated pen plotter depicts sounding tracks, selected sounding values, and other graphic reference information for the hydrographer's use during data acquisition operations. The plot, intended for momentary use only, will not be retained as part of the permanent survey records. The relatively narrow (22-inch) roll paper permits viewing of a reasonable portion of the plot while it is being generated. The plot contains reference and past survey data and serves to indicate vessel position and survey progress as data acquisition proceeds.

The left/right indicator gives the vessel helmsman steering guidance along specified survey tracks or toward specified waypoints; it may be integrated in a more comprehensive display such as a remote display of the hydrographer's CRT screen.

The magnetic tape cartridge record/playback device serves the two-way data transfer functions between DAS and DPS. Before data acquisition operations are begun, a prerecorded tape of computer programs and DPS data is read into the DAS; this data includes various project parameters, equipment and position control information, plotting parameters, shoreline and other reference information, and specified survey line scheme parameters. Once the input tape has been read and the information assimilated by the DAS, a blank tape cartridge is inserted in the recorder and data recording can begin.

The functional performance characteristics of the DAS are described by the system's operating modes and its automatic and selectable input and output functions; the relationships between modes and functions are depicted in matrix format in figure 2.

The DAS is placed in operation in the INITIALIZE mode in which the following tasks are performed:

1. Diagnostic routines are run to assure that the DAS is functioning properly.

2. Computer programs and DPS data are read from the prepared tape cartridge.

3. If required, the background plot of grid lines, shoreline, annotations, and other reference information is generated on the DAS plotter from the prepared tape cartridge.

4. The hydrographer, interacting with the computer, enters, verifies, or updates required survey parameters and reference and descriptive information.

5. Header information is recorded at the beginning of the blank data tape.

With the initialization sequence completed, the DAS shifts to the IDLE mode. In this mode no navigation (NAV), heave/roll/pitch (HRP), or depth (DEP) data is recorded, but some of the selectable input functions may be invoked. In IDLE mode the functioning of the sensor systems and the data received from those systems may be verified; navigation information is computed and displayed and may be used to steer the survey vessel to the place where survey operations are planned to begin.

LOGNAV mode is initiated when the performance and adjustment of the navigation and HRP sensor systems have been verified and "good" NAV and HRP data are consequently available. This verification is performed by a calibration routine (CALNAV) which is recorded on the data tape. In LOGNAV mode, NAV and HRP data are recorded continuously, and, since the DAS will not be shifted back to IDLE mode until survey operations are terminated, a continuous record of NAV and HRP data is obtained for the entire data acquisition. This record is used in later processing to analyze positioning accuracy and to reconstruct the entire survey track.

When DEP data is required, the hydrographer initiates SOUND mode, which merely adds to LOGNAV mode the recording of digital depth sounding data. Generation of INDEX numbers (formerly Position Numbers) is activated automatically in this mode; these numbers address selected data groups in post-processing. The distinction between LOGNAV and SOUND modes that identifies depth data production periods among other periods is primarily intended to aid post-processing.

In normal sequence, the DAS advances from INITIALIZE to IDLE to LOGNAV mode as survey operations are begun. During the operations period frequent shifts are made between LOGNAV and SOUND modes, and the system is returned to IDLE mode only when operations terminate. At this last shift a management report is generated that may include total miles run, Index numbers used, etc.

The DISPLAY function includes various CRT displays that may be selected by the hydrographer or are generated according to the operating mode, the task, or the function being performed. A standard (or default) display in

the LOGNAV and SOUND modes uses one part of the screen to display all, continuously updating NAV, DEP, HRP, and TIME data together with computed information, other parameters, and status or alarm indicators. The rest of the screen is used for communication between the hydrographer and the computer system.

The NAVIGATE function includes computing the vessel's position using data received from the navigation sensor systems, displaying the position values and computed course and speed, and providing position information to generate plots. Position information is generated in XY grid coordinate values or, optionally, in geographic coordinate values. The NAVIGATE function is performed on the basis of only two lines-of-position specified by the hydrographer. However, tests are performed on all data received from the sensor systems to assure data validity, to alert the hydrographer to inconsistencies, and to aid the hydrographer in diagnosing and correcting such problems.

The RECORD NAV AND HRP DATA function records on magnetic tape all data values received from the navigation and heave/roll/pitch sensor systems and such values manually entered by the hydrographer. Up to four sources of positioning data (or lines-of-position) together with field determined correctors can be recorded as well vessel heading and speed and computed approximate positions derived from the NAVIGATE function. All values received from the various sources are recorded with an appropriate tag for the time of measurement.

The RECORD DEP DATA function indicates that all measurement values from the echo sounding sensor system are recorded on the magnetic data tape.

INDEX NUMBERS are generated, displayed, and recorded while DEP data are being acquired. The numbers are unique within the survey project but are independent of survey sheet limits and generally independent of plot scale. Although the index numbers duplicate information available from the unique combinations of vessel identification and time, they require significantly fewer numeric characters and are thus a more efficient tool for addressing selected group of data later.

STEER is an output function that provides the helmsman with displayed information to steer the vessel along a predefined straight or curved survey line or toward a designated location. The DAS accepts parameters to define a pattern of lines, commonly a series of parallel straight lines, and retains those parameters indefinitely. Since each line in the pattern has a unique identification code, the hydrographer can simply designate the particular line that is to be steered.

The PRINT function may be activated by the hydrographer to record selected data or information on the DAS printer. In like manner, the PLOT function may be used to generate a graphic, two-dimensional plot of the vessel track and selected sounding values along the track on the system's plotter. Printout records and plots generated by these two functions are intended for use only during survey data acquisition operations and are not intended to be retained as permanent survey records.

PARAMETER UPDATE permits the hydrographer to change parameter values or other information stored in computer memory at any time. The NOTE function is used to record hydrographer's notations on the magnetic data tape for future reference or report generation.

CALDEP and CALNAV are functions for executing and digitally recording calibrations of the echo sounding sensor system and the positioning sensor systems, respectively. Both are computer program controlled and, once initiated, automatically direct certain actions to be taken or particular information to be entered by the hydrographer. In their present concepts, the two functions generally replicate the "barcheck" routine and the customary routines for positioning system calibrations.

Finally, the DP, or Designated Position function, marks a specific event or observation at an instant in time in the continuum of navigation and depth data being recorded and identifies it for particular attention in postprocessing.

In summary, the DAS is designed solely to acquire hydrographic data, to accommodate a variety of possible sensor system inputs (including up to four lines-of-position and heave/roll/pitch data), to record all available pertinent information in machine processable form, to aid the hydrographer in acquiring survey data through various guidance mechanisms, and to test for data validity. Navigation data are recorded to establish the vessel's track throughout the survey period while depth data is recorded only when required.

DATA PROCESSING SYSTEM

The functional hardware configuration of the DPS is depicted in figure 3; once again, the technical details of the components, interfaces, dimensions, installations, etc., are not addressed here. The DPS computer is anticipated to be a minicomputer capable of supporting software operating and data base management systems, multiprogramming and multitasking, and a variety of input and output peripheral devices. Winchester technology disk drives provide the computer with random access storage capacity for all software programs and all data associated with a survey project. The magnetic cartridge tape drive represents the communication link between the DPS and the DAS; 1/2-inch magnetic tape drives provide the communication link with other computer systems that provide historical and reference data to SDS III or use data from SDS III.

The system's users will share a single plotter and a single line printer. The plotter will be able to generate a graphic plot of the customary dimensions of a survey sheet. It has not been decided whether the plotter will be of the "pen-writing" type that permits multiple color plots but involves considerable plotter operating time, or of the "electrostatic" type that limits the plot to a single color but reduces plotter operating time. In either case, the DPS-generated plots will not be of archival quality, and final plots will continue to be generated at Marine Center facilities. The printer, which uses standard-sized computer printout paper, will print data

listings and various reports. A single digitizer for shared use converts any graphic data to digital, machine processable form for storage and further use. A particular application of this is the conversion of shoreline data from topographic sheets and charts.

Finally, the DPS accommodates up to four simultaneous users by means of terminals that consist of a CRT display and a keyboard. Although one or more of these terminals may eventually be replaced by graphics terminals, the present design incorporates line-text type terminals with only limited graphics capability, specifically, the ability to display points in a two-axis coordinate system. The latter capability is necessary to inspect or edit the time series data that are characteristic of survey data. The display of spatially distributed data is left to the plotter facility. One paper "hard-copier" may be attached for shared use by the four CRT user terminals.

The functional performance characteristics of the DPS may be grouped in the broad areas of (1) hydrographic data reduction, (2) data storage, and (3) utility functions. Of these, hydrographic data reduction is of primary interest. Since it manifests the present evolution of data treatment, it is described in detail below. The DPS has the capacity to store all survey project data at all times, organized and filed for retrieval according to geographic areas, types of data, and source codes. Utility functions include the geodetic and coordinate conversion capabilities that now exist in HYDROPLOT and the required routines for computing sound velocity values, to establish systematic effects models for positioning systems, to compute tide adjustment values, and to manage instrument correction data. Other utility functions may be added in the future.

Hydrographic data reduction, or the processes to derive survey product data from raw hydrographic data, is depicted in figure 4. Although the following description of data flow would indicate a single pass of data through the reduction process, it is understood that various portions of the process will be repeated as more definitive information becomes available, for example, in the areas of instrument correctors, sound velocity and tide adjusters, and systematic effects of positioning systems.

Referring to the diagram, input data to the hydrographic data reduction process are identified across the top: Field Positioning Data, Designated Positions, Field Depth Data, and Field HRP Data. The processing steps for each of these data groups follow in the vertical columns directly below the input headings. The heavy line horizontally across the diagram separates the upper region of processes that involve all acquired data from the lower region of processes that involve only data at specified instances of time. As indicated, the ultimate result of the overall process is the position of a data point and the depth value or graphic symbol of that data point. The time of the data point serves only to correlate various data sources and is thereafter of only passing interest.

Field positioning data include the complete time series of LOP values, other navigation data, approximate positions computed during data acquisition, and CALNAV results. In analyzing these data, through interaction with the

computer, the hydrographer will correct for any incremental LOP value errors such as lane jumps, update systematic effects models, and correct LOP values for random effects such as momentary value jumps and high frequency "noise" in LOP values. The approximate vessel track is updated for any significant alterations resulting from the analysis. This track is used for selecting data (soundings) commensurate with survey data density/scale requirements. Other inputs to the selection process are the Designated Positions and all sounding values obtained during data acquisition.

Field depth data includes the time series of sounding values and the results of CALDEP routine performed during acquisition. Analysis of this data, in much the same manner as that of positioning data, leads to sounding values filtered and corrected for random effect errors and updating of instrument correction files. In addition, the sounding values are corrected for vessel heave, either by application of directly measured heave values from HRP data or by other, mathematical methods. The product of the sounding selection process (more correctly, the data point selection process) is a series of particular time instances for which the remaining computations are made.

The position computation is based on the LOP values at the exact data point time. With time and the associated approximate position known, the values of any corrections for systematic effect errors are determined and applied to the LOP values. The position of the sounding transducer is then computed with appropriate adjustment for any geometric offsets between the positioning systems antennae and the transducer on board the survey vessel. Finally, and only when necessary and possible, any offset between the transducer position and data point position is applied to arrive at the desired data position. This last offset may, for example, result from a narrow sounding beam aimed in a direction other than vertically below the sounding transducer.

The desired depth value at data time is obtained by applying a variety of algebraic correction and adjustment values to the initial sounding value. Instrument corrections include those pertaining to the echo sounding instrument as well as the static and dynamic draft values associated with the survey vessel. Sound velocity adjustment may be a simple adjustment for variations in the acoustic velocity in the vertical water column or a more complex adjustment for acoustic raypaths traveling away from the vertical. Tide adjustment is determined by entering the tide model with data time and position.

Computations using HRP data are performed for the sole purpose of obtaining adjustment values for position or depth computation. The application of heave values is self evident. Roll and pitch, together with heading, establish the attitude of the survey vessel at every instant; this information is used to refine the geometry between positioning system antennae and sounding transducers and to establish the pointing direction of the sounding beam. Designated Positions may designate particular depth measurements or some other data point; in the latter case, a cartographic symbol will commonly be specified in coded form.

In summary, the DPS is designed to expedite data processing by allowing several users to conduct their transactions at the same time and by providing efficient output capabilities while, at the same time, allowing for advances in the methods of surveying and data manipulation. It is intended to serve the data operations and management needs for an entire survey project in an integrated manner.

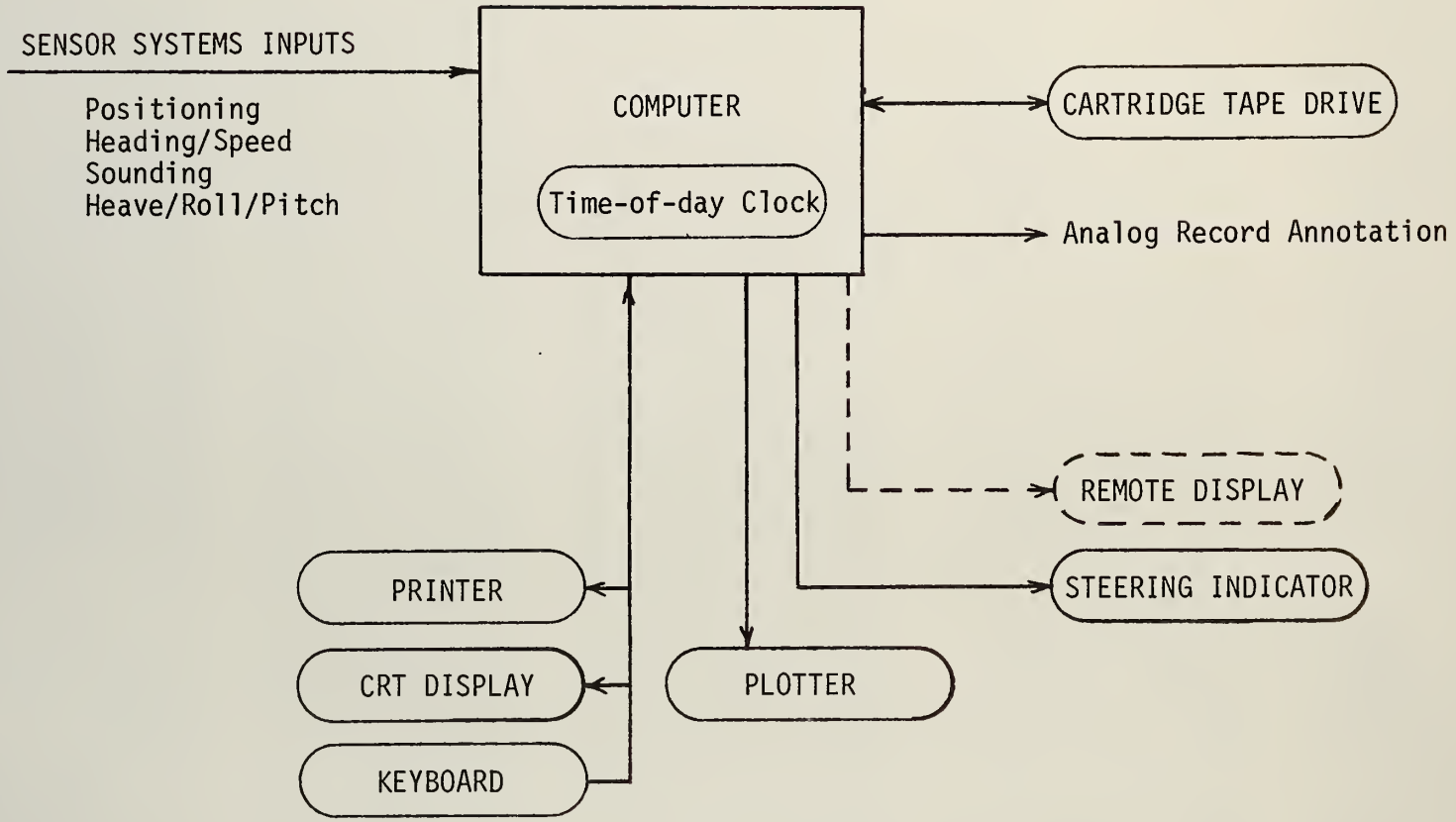

Figure 1. DAS Functional Hardware Configuration.

		MODES			
		INITIALIZE	IDLE	LOGNAV	SOUND
Automatic Functions	DISPLAY	X	X	X	X
	NAVIGATE		X	X	X
	RECORD NAV & HRP DATA			X	X
	RECORD DEP DATA				X
	INDEX NUMBERS				X
Selectable Output Functions	STEER		X	X	X
	PRINT	X	X	X	X
	PLOT	X*	X	X	X
Selectable Input Functions	PARAMETER UPDATE	X	X	X	X
	NOTE	X	X	X	X
	CALDEP		X	X	
	CALNAV			X	X
	DP			X	X

* Background plot only.

Figure 2. DAS Modes and Functions.

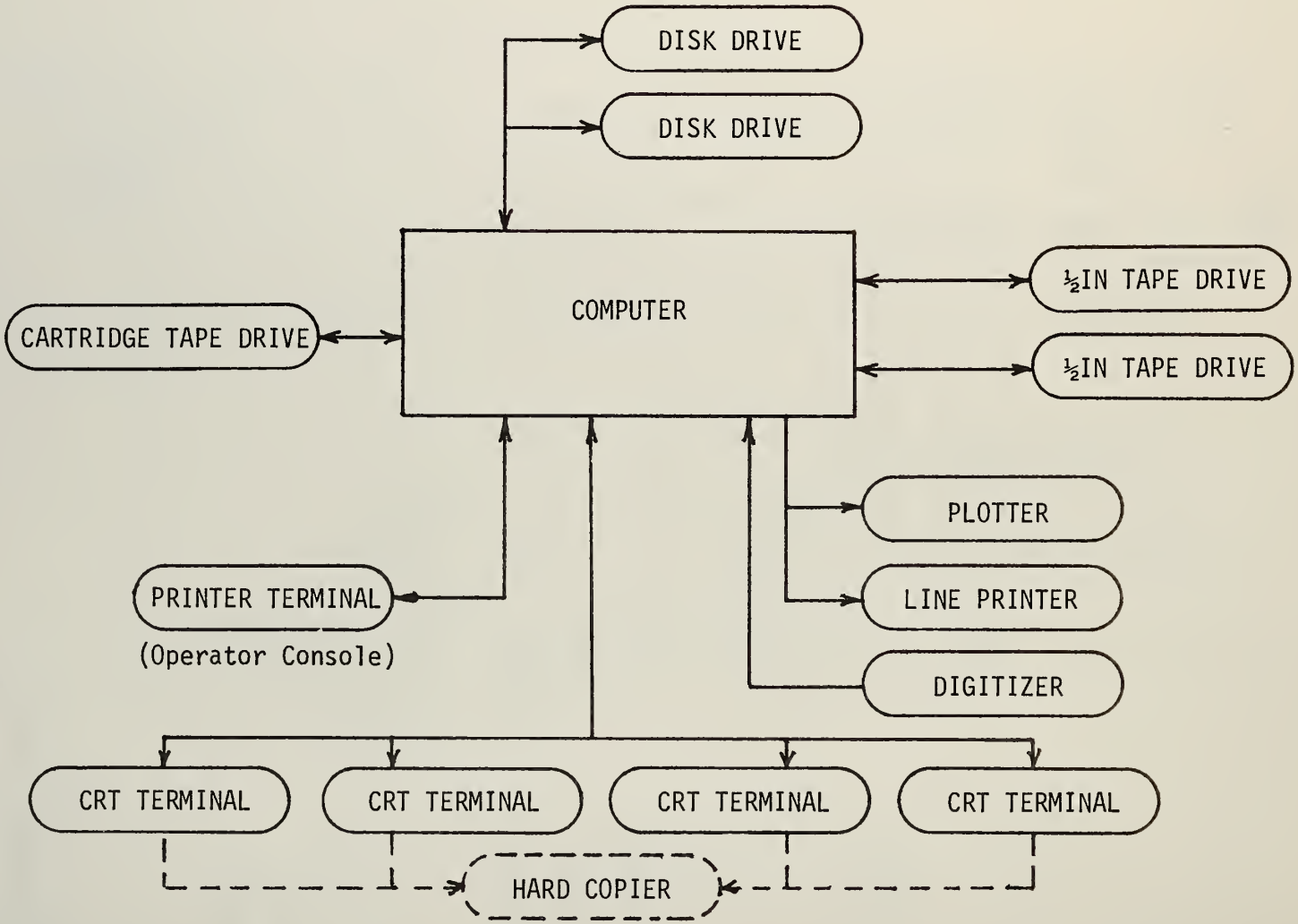

Figure 3. DPS Functional Hardware Configuration.

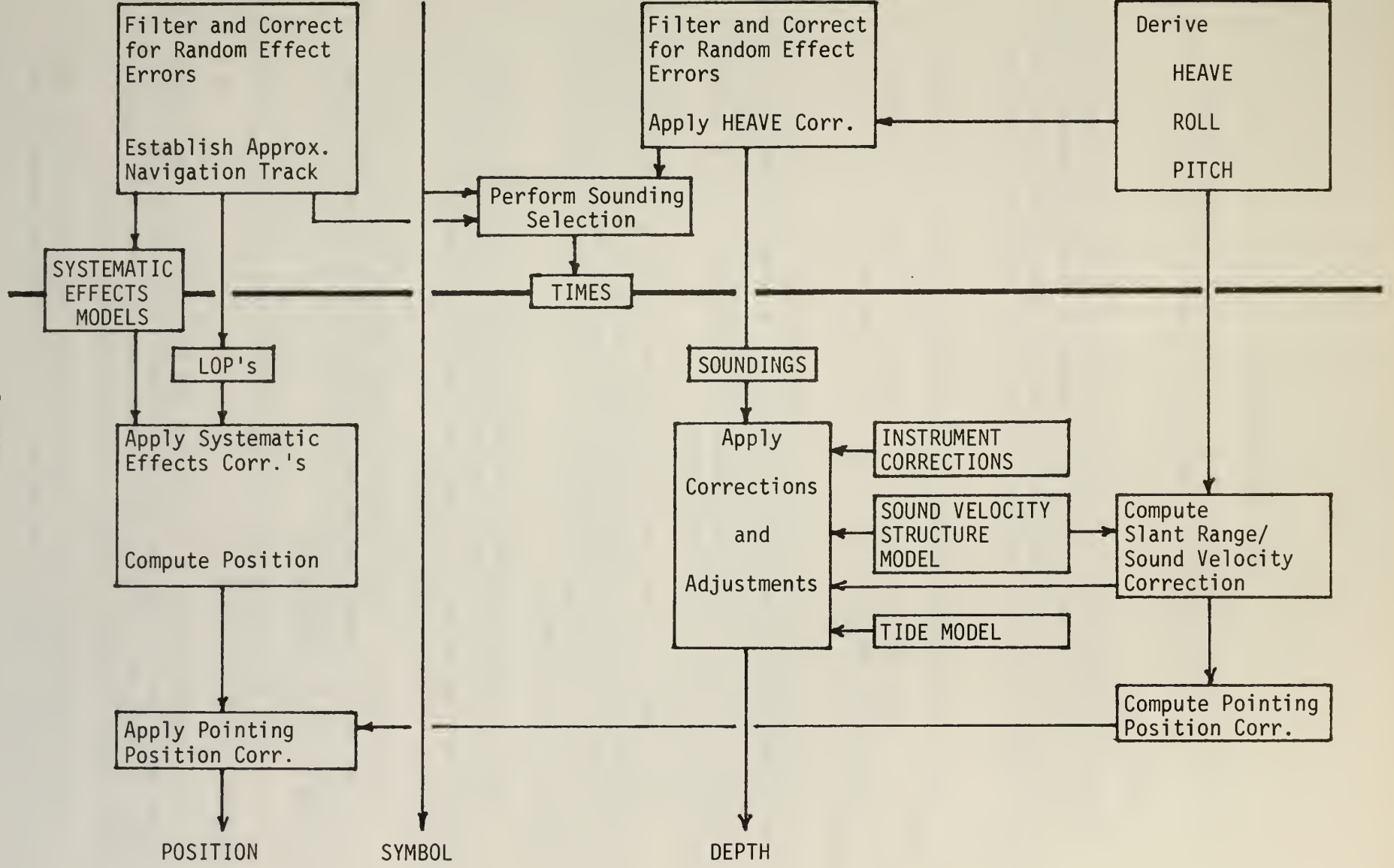

Figure 4. Hydrographic Data Reduction.

CDR VANDERMEULEN: I will be happy to answer any questions.

Thank you.

CDR SCHAEFER: John, I would like to ask one question of you. Realizing that resources are limited and may not be forthcoming in the immediate future, but providing that they do show up out of someplace, what sort of an implementation plan might we expect in terms of when would this system be on line in the field?

I know you and I have discussed this, but perhaps you could address this briefly.

CDR VANDERMEULEN: ALL right. Did you put me on this firing line on purpose, Glen?

As I mentioned in the beginning, the project is under the auspices of the Office of Marine Operations, Admiral Munson. So the project management office is located there. It is certainly anticipated that a procurement of a system like this, being as how it is an ADP procurement, would require at least a year from the delivery of a procurement specification.

The preparation of that specification has been worked on during this year. We have certainly arrived at the general concepts of the system. My personal estimation would be, and I talked with Rich Schiro the other day, that it would certainly take six months of some dedicated effort on the part of several capable people to complete the specifications.

So, stacking that together, you're looking at least a year and a half from today, given that kind of initiative. I think the anticipation of funds for 1982, which had been the earlier plan, is today not too good, and we are having to look at fiscal year 1983 for funding initiative.

With the front end loading relieved, we now have time to fully develop our concept and to assemble the project management staff and write the specification. But you are certainly looking at the fall/winter of '83/'84 before you can hope to have any hardware.

LT DOUGLAS G. HENNICK, FAIRWEATHER: What's the problem with developing heave, roll, pitch indicators?

CDR VANDERMEULEN: I'm not sure that there is a real problem there. There has been an initiative. A heave, roll, pitch sensor was developed by Datawell, a Dutch company, for the BSSS system. It weighs on the order of 250 pounds and must be a good 15 gallons in volume. It's far too large for a launch.

From a hydrographic point of view, we usually relate to the launch system as the requirement. Ships can handle lots of things, but launches are the ones

that do most of the production and pitching and rolling.

The effort to generate a heave, roll, pitch sensor for launches has stalled for the moment, partially because of a lack of our ability to pay attention to it.

I believe the potential is there, particularly if we can get somewhat closer collaboration between development engineering offices and ourselves, the hydrographic requirements people, to trade off the constraints of reliability, volume size, power consumption and the finesse to which it can measure.

At the moment, there is not an active effort in progress.

LT HENNICK: No major problems, though, for launches?

CDR VANDERMEULEN: I think the problems are surmountable.

NATIONAL OCEAN SURVEY
NEXT GENERATION TIDE AND WATER LEVEL MEASUREMENT SYSTEM

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ABSTRACT

The present National Ocean Survey tide and water level measurement system is labor-intensive to operate and maintain with relatively high maintenance costs and low reliability. These factors, coupled with recent measurement and recording technology advances, have led to the development of a next generation tide and water level measurement system.

Present Inventory

The National Ocean Survey (NOS) presently has an inventory of 1,000 analog-to-digital recording (ADR) and analog tide and water level gages manufactured by Fischer & Porter Company and Leupold & Stevens, Incorporated and 350 gas-purged pressure recording (bubbler) gages manufactured by Metercraft Corporation and Bristol-Babcock Division, Acco Industries, Incorporated, plus a few "standard" analog gages. An average of 300 ADR gages and 100 bubbler gages are in operation at any one time for tide measurement and 50 ADR and 40 analog gages for water level measurement (on the Great Lakes).

The NOS began using the bubbler gage in 1960 to satisfy a need for a portable gage to support hydrographic surveys. NOS engineers developed the gage from a design by Alfred C. Redfield of Woods Hole Oceanographic Institute.

The NOS began using ADR gages manufactured by Fischer & Porter Company in 1965 as a result of a policy decision in 1964 to use computer assisted data analysis techniques (the ADR gage produces a paper tape record in machine-readable format) and because of increasing difficulty in acquiring parts for the "standard" gage. The Fischer & Porter ADR was then phased into the inventory as the standard gage was phased out, and in 1975, NOS began adding Leupold & Stevens ADR gages to the inventory.

Is a New System Needed?

Several factors which influence the measurement system have changed since the adoption of the present systems. The demand for tidal data and data products and the amount of data collected annually have more than tripled during the past 10 years due to the increased interest in and use of the coastal zone. These additional data are required for marine boundary and jurisdiction determinations, engineering projects, and scientific uses. During the same period, labor costs have increased dramatically while Federal policies are now apparently aimed at providing services using less Federal personnel. The NOS field offices, which were previously able to devote a portion of their time to maintenance of tide stations in their geographic regions, have closed and been consolidated into one office for the west coast, Alaska, and the Pacific Islands, and one office for the east and gulf coasts and the Caribbean.

The existing, essentially mechanical, measurement system is labor intensive with relatively high maintenance costs and low reliability, and one of the system manufacturers has stopped producing the gages. Data products are not getting to the user in what the user considers a timely manner. System operation and maintenance costs have increased 60 percent durng the past 3 years. A review of the data analysis system in 1974 by the NOS ADP Programming Branch suggested that the major contributor to data analysis problems was the data acquisition system. A study of 6,000 station-months (1 month of data from 1 tide station) of tide data in 1978 indicated that 50 percent of the data had defects which required from 2 to 5 times as many analysis staff-hours as defect free data. The study also indicated that nearly one-half of this 50 percent could not be turned into final data products. Measurement and recording technology have changed significantly since the early 1960's. The above factors, considered together, led to the next generation development effort.

New System Progress to Date

The following major events summarize the next generation system development effort for the past 3 years.

May 1977	Budget request submitted for Fiscal Year 1980 budget for resources to support the development and implementation of the next generation system.
August 1978	Market survey of commercially available equipment that might satisfy the next generation requirement was initiated.
October 1978	Office of Oceanography formally requested assistance from the Office of Marine Technology (now Ocean Technology and Engineering Services) in the development of the system.
December 1978	Next Generation Tide and Water Level Sensing and Recording System Performance Requirements study begun.

June 1979	Requirements study completed and circulated for comment.
August 1979	Market survey completed.
September 1979	Decision for three-phase contracted development effort. Phase 1 - Development of conceptual design and functional specifications for tide and water level measurement system. Phase 2 - Development and testing of prototype units. Phase 3 - Development of production units.
September 1979	Statement of Work for Phase 1 contract begun.
October 1979	Error analysis of existing and potential systems initiated.
March 1980	Statement of Work for Phase 1 contract completed.
April 1980	Request for Proposals for Phase 1 issued.
August 1980	Phase 1 contract awarded to Raytheon Ocean Systems Company.

The market survey, requirements study, and Phase 1 contract are discussed below. The market survey resulted in responses from 18 manufacturers and for 34 systems. The information requested from the manufacturers and generally provided included:

(1) Subsystem Background Information

a. Manufacturer
b. Model Number
c. Date first manufactured
d. Number sold to date

(2) Measurement Principle

a. Transducer type
b. Quantity measured
c. Deployment configuration

(3) Measurement Performance Specifications

a. Range
b. Resolution
c. Accuracy
d. Time Response

(4) General Performance Information

a. Data sampling rates and duration
b. Total record duration
c. Data recording methods
d. Data reduction and analysis procedures
e. Manufacturers recommended usage

(5) Environmental Specifications

a. Operating environment
b. Shelter requirements
c. Temperature range
    1. Operating
    2. Storage
d. Fouling/corrosion protection

(6) Physical Characteristics

a. Weight and power supply
b. Dimensions
c. Construction materials

(7) Subsystem Test, Calibration, and Performance Monitoring

a. Built-in test jacks
b. Test point jacks
c. Special test equipment
d. Transducer signal availability externally
e. System operational performance monitoring
f. Calibration philosophy

(8) Miscellaneous

a. Approximate cost
b. Warranty
c. Availability of spare parts
d. Suggested maintenance cycles and replacement parts

The requirements study considered the following areas:

Mission
Products/Applications
Leveling and measurement reference
Calibration and measurement drift check
Range of tide/water level
Environment
Reliability
Integrated Logistics Support
Service intervals/requirements

Sampling frequency
Electrical power
Compatibility
Human factors and packaging
Electrical power
Compatability
Life cycle costs and cost effectiveness
Installation

The most important tasks of the Phase 1 contract are the identification and evaluation of sensor technologies, the selection and further development of four of the sensor technologies, the identification and evaluation of recording technologies, the system design, and the preparation of functional specifications. Six different physical properties of water or other materials with potential for determining water surface elevation have been considered in the identification and evaluation of sensor technologies--bouyancy, pressure, acoustic, electrical properties, electromagnetic properties, and geometric optics. Six sensor techniques--surface following, surface penetrating, pressure sensing, acoustic, radar, and laser--and 19 sensor types using these techniques have been evaluated. Float and wire, strain gage pressure, contact closure staff, and air acoustic have been chosen for further evaluation. Four recorder technologies were considered--magnetic tape, magnetic bubble, solid-state semiconductor memories, and paper tape. Twelve recording techniques were evaluated and two have been selected for further evaluation--Ultraviolet Programmable Read Only Memory and cassette magnetic tape recorders.

Future Timetable

The Phase 1 contract is scheduled for completion in June 1981. The Phase 2 contract for development of prototype systems will be awarded in Fiscal Year 1982. Prototype test and evaluation are scheduled for Fiscal Year 1982 and 1983 and the phased implementation of the new operational system into the NOS tide and water level data collection network is scheduled for 1983 through 1990.

DISCUSSION

LCDR SPILLMAN: Does anyone have questions they would like to bring up at this point?

CDR CARL FISHER, Chief, Operations Division, Atlantic Marine Center: I'll start off the morning's questions. I was wondering about the application of this to hydrographic units. I believe that quite often it would be of quite value to have the primary station that's part of the project to be tied in, and I notice with a interdate and all, we can't really expect that on a ship. Is there a way we can get this information to the ship?

LCDR SPILLMAN: That's a good question, Carl. The system as designed, the remote unit as designed, was set up for a relatively permanent station. It requires an instrument shelter, so it's not really applicable to a shore-term tides station.

But to get to your question, the data from the primary station could be provided to vessels. Probably the simplest way to do it right now would just be to give us a call, and we will read it to you.

I'm sure there are other techniques that could be used. If we could set up some type of receiver aboard the ship or if you can get to shore and hook into a telephone line, we could certainly send it over a telephone line. But right at this moment the easiest wasy to do it would be to give us a call and we will read it to you over the phone.

CDR FISHER: Thank you.

CDR JOHN VANDERMEULEN, Officer of Marine Surveys and Maps: I have two questions, Don. One is do I, in fact, understand that you have two-way real time communication via satellite? In other words, can you transmit instructions to the station and get immediate reply whether it responded?

CDR SPILLMAN: Yes, you understand correctly.

CDR VANDERMEULEN: Okay. The other one is the sampling, you say six-minute tide observations, water level observations. Are those instantaneous readings, or does the system do some measure of processing to find the best answer at that interval?

CDR SPILLMAN: At this point they are instantaneous readings.

CDR VANDERMEULEN: Thank you.

CDR SPILLMAN: Other questions?

Thank you.

MR. DIXON: Thank you, Don. It's quite a change from the old tide board nowadays.

NOS WATER LEVEL MEASUREMENT SYSTEM INTEGRATED LOGISTICS SUPPORT PLAN

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ABSTRACT. The National Ocean Survey Water Level Measurement System Integrated Logistics Support Plan (ILSP) is a systematic method of supporting the measurement system to ensure that the system's operational capability is maintained at an optimum level throughout the service life of the system. Implementation of the ILSP will impact hydrographic field units but should result in fewer instrument failures and other problems.

INTRODUCTION

The purpose of this presentation is to present an overview of the National Ocean Survey (NOS) Water Level Measurement System Integrated Logistic Support Plan (ILSP). I emphasize overview, rather than the detailed nuts and bolts of the plan. I want to familiarize everyone with why and how we have come to the point of having an ILSP and to explain what ILSP is.

Virtually everyone here who has been aboard a NOAA vessel in recent years is familiar with Integrated Logistic Support and FAILogs. I want to address specifically the Tide Gage ILSP and even more specifically, I want to address the role of ILSP in hydrographic surveying and how it will affect the hydro vessels and hydro parties.

WHAT IS ILSP?

Integrated Logistics Support Plan (ILSP) is a process which identifies the functions and resources required for systematic and orderly support of any system. The term "Logistics" may be defined broadly as the function of acquiring, packaging, preserving, transporting, distributing, storing, and maintaining the resources of material, manpower, services, and facilities associated with a specific system to:

1. Initially attain the system's operational capability, and

2. Assure that such operational capability is maintained at an optimum and economical level throughout the service life of the system.

The concept of intergrated logistics support was developed by the Department of Defense to provide a mechanism for the acquisition of large weapon systems. The principles of ILSP are valid even when applied to the smaller scale NOS projects, such as the acquisition of tide measuring equipment. The acquisiton of the Next Generation water level gage is following an "engineering management" approach, of which ILSP is part.

Unfortunately, the Fischer & Porter and Leupold & Stevens tide gages were not acquired under those conditions. Therefore, the ILSP for those systems was formulated after the systems had been deployed operationally for many years. Nevertheless, the ILSP developed for the NOS Water Level Measurement System does include the functions and resources to operate and maintain the present system.

The ILSP was a natural outgrowth and a planned result of the Pilot Program instituted in 1978. The Pilot Program was spurred by a large amount of defective data collected primarily with the Leupold & Stevens tide gage. Analysis of the defective data indicated design deficiences of the instrument for the highly saline environment into which we put it. The Pilot Program tests focused initially on identification of problems and corrective measures to solve the design deficiencies. These corrective modifications included upgraded bearings for the encoding drums, battery voltage monitors, improved springs, and a 6-inch float well for a larger float. The scope of the Pilot Program was not limited to Leupold & Stevens gages. The persistent Fischer & Porter problems, such as punch blocks and faulty code discs, were also addressed and improvements made.

While the immediate goal of the Pilot Program was to take corrective action, an equally important task was to document and standardize preventive maintenance and test procedures to monitor gage and station performance. This is where field personnel fit into the picture, that is the implementation of the ILSP. I will come back to this.

I would like to take a moment to give the history of ILS related to the NOS tides programs. This can be discussed in four phases:

1. Prior to 1972,

2. 1972 - 1978,

3. 1978 - 1980, and

4. 1981 to the future.

Let me elaborate somewhat on these phases. First, the "Blue Book" study of 1972 identified problems, documented needs for urgent changes, and made recommendations. The Blue Book study resulted in a system that reported failures via the FAILog system, primarily for equipment other than tide gages. From 1972 to 1978 we operated in a mode with very little participation in the FAILog system for tide gages. While the FAILog reporting program in itself did not provide the answer to the tide gage maintenance problem, it did provide a foundation on which to build and expand. Between 1978 and 1980 the Engineering Development

Office (formerly EDL), working with the Office of Oceanography, developed the Pilot Program and a draft ILSP. Out of necessity to solve the most urgent problems, emphasis was placed on the ADR gages.

In 1980 we finalized the four volumes of the ILSP and issued the first revision. The tide parties of both Marine Centers and contractors started actively using ILSP and FAILogs in 1979. In 1981 we enter into the period of full implementation with the incorporation of the ILSP and FAILog procedures into the Hydro Survey Project Instructions. One of our objectives of 1981 and 1982 is to expand and improve the ILS procedures for the pressure (bubbler) tide gage. We have already seen and measured an improvement of data quality with the implementation of ILSP at control and subordinate tide stations by the tide parties and contractors. Our analysis program is realizing the results of a reduced number of data defects. If you can reduce the number of data defects on each roll, the impact can be significant. For example, in calendar years 1979 and 1980 there were 284 and 200 station months of hydro data, respectively. It is projected that in 1981 there will be 240 station months of hydro data and tide and tidal current data. It is important that the quality of this data be as high as possible not only from an analysis standpoint, but also in regard to the final product of the hydro chart.

As part of our analysis and data evaluation process we have revised the preliminary evaluation form. I mention this because it is contained in the ILSP and all tide data will be subjected to these new evaluation criteria. The preliminary evaluation serves two basic purposes. First, under the revised procedures it provides for a much more objective evaluation of the data quality and data defects for feedback to the field. The second purpose of the evaluation is for a quantified evaluation of gage and modification performance, defects, and effectiveness.

We have included in the ILSP a diagnostic key to assist field personnel and our analysts in the office to identify data defects and associate the probable cause for the data defect. Hopefully, you will use this symptom/cause key while you conduct your initial data scan or while actually using the data and take immediate corrective action to fix the problem.

This data evaluation information is entered into our computer which computes data defect factors. These factors are very useful in evaluating program performance, especially when combined with FAILog data. I will come back to FAILogs in a moment.

Now I would like to introduce you to the ILSP document itself. All Hydro ships and Tide and Tidal Currents ships were sent relevant portions of this document several months ago. It is an awesome-looking document and I will not get into the nuts and bolts of all the tests. We will leave that to the tides officers and survey technicians. By the way, there will be a formal training class each year at AMC and at PMC on all aspects of the Tides program. The procedures for ILSP and FAILogs will be taught in those classes along with all other aspects of tides training. I would encourage you to take advantage of

this training by sending your tides officers, operations officers, and technicians who will be using this on a day-to-day basis. The training agenda has been formalized and will emphasize those items that can significantly improve data quality. I also encourage the CO, XO, and operations officer's enthusiastic suppport of these new procedures.

The format is seven chapters in two volumes. Chapter 4 is the Maintenance Support section. The other six chapters deal with the concept of ILSP, Operational Descriptions of elements of ILSP, Data Quality Standards, FAILogs, Logistics, and Training such as slide/sound presentation for Field Verification Tests, observers duties, etc. (An additional three volumes contain Engineering Specifications, Users Guides, and Parts Manuals for reference.)

The Hydro ships and parties and Tides and Tidal Currents ships have received Chapter 3 on quality standards, most of Chapter 4 on Maintenance Support, Chapter 5 on FAILogs, and Chapter 6 on Logistics. Chapters 4 and 5 are the ones that will affect your operations most and will require your active participation.

The tide gages you receive for this year's field season will be refurbished gages. They will not all be modified. It is planned that most of the gages will be Fischer & Porter rather than Leupold & Stevens. We are planning that next year all your gages will have received the modifications such as modified punch blocks, code discs, stronger springs, and new timers. One reason for not routinely issuing the Leupold & Stevens gages is they now require 6-inch diameter float wells and a larger float. This requires adapter plates to the 4-inch base plates, which are currently in short supply.

The gages will be adjusted to specified punch force settings which have passed rigorous acceptance testing standards. It will be up to you to perform the Field Verification Tests or preventive maintenance to detect a deterioration of performance, as well as perform corrective maintenance. The Field Verification Tests are conducted quarterly and include operational inspection, torque tests on Leupold & Stevens gages, punch force tests, and other component tests.

The ILSP is very specific about field level maintenance versus shop level maintenance and indicates a recommended course of action. Pass/fail criteria are used to indicate what should be repaired in the field. It also requires documentation of repairs or tests via a FAILog.

One could have some serious misgivings about all this and could have some reservations about full participation in this program due to:

1. HQ requiring more work in the field - preventive maintenance.

2. HQ requiring more paperwork from the field - FAILogs.

3. Stricter evaluation and harder review of data quality.

I ask that you consider the beneficial aspects of participation. It has been demonstrated by the tides parties and operation and maintenance contractors that participation in and compliance with the letter and intent of ILSP do improve data quality. Next, it closes the loop between the field personnel and the office personnel who have to use the data. It also allows analysis of failed parts and observer's errors because we now have a mechanism to relate the data defect codes determined during evaluation with the documented corrective action taken to fix the problem. The procedures to fix most errors are documented in the manual which standardizes our methodology. When carried to its intended end, and as our data base expands, this system will allow us to determine Mean Time Before Failure of certain parts for preventive maintenance. When integrated with good overall station installation and maintenance practices, User's Guide, and the Project Instructions, ILSP will definitely improve the data quality, our data acquisition system, and the resulting data package. The Tides pesonnel at Rockville and the Marine Centers are doing all we can to make the data acquisiton and ILSP more versatile. We are revising the FAILog to make it conform better to the tides situation; we are standardizing part lists and code entries for rapid completion of the form. But most of all we are using the information that is being generated by the ILSP.

Let me close by asking your cooperation and support to see to it that the intent of the ILSP is fulfilled.

MR. MASTERSON: Any questions?

CAPT E.K. McCAFFREY, Special Assistant for Engineering Technology, Rockville: I don't have a question for you, Bob. I want to compliment you on your excellent presentation of ILS and its application to the water level system. I have a comment or bit of information for the audience assembled here.

Back in April of 1980 the Director of NOS commissioned the Systems Analysis Division of what was then the Office of Marine Technology to make a study of ILS and its application to all of the NOS program areas. It's my understanding this group has now -- and there are a good many of the people in the program areas participated with this group. They are about ready to go to press now and present their findings to NOS top management, and that will probably happen sometime this month.

MR. MASTERSON: Great.

CDR FISHER: Good morning again. One thing that I thought about during this presentation, and it's keyed very specifically to us at NOS and there are quite a few other guests here, and that is, you know, we cite certain manufacturers that we purchase from, and then indicate the extent that we have gone to make these operational.

And I think it might give a little perspective if you would just share with us what these gauges were originally designed for, why NOS had to assume such responsibility to make them operational.

And then, if you could, also give us an indication the quantity of these in NOS, and possibly one area I could think of is like USGS, to show how extensively they have been brought in for water level measuring.

MR. MASTERSON: Fine. The Leupold Stevens tide gauge particularly has been operated or used by the U.S. Geological Survey -- let me back up. The Leupold Stevens water level measurement gauge was used by the U.S. Geological Survey in quantities of thousands. Typically, they used them in a large, corrugated metal float well. They had rather large floats on them. They were also used in fresh water.

The National Ocean Survey purchased some gauges, Leupold Stevens gauges. They put them in the field in a highly saline, estuarine environment, oceanic equipment.

After considerable time, a year to two years, we found that the bearings in particular were not of a nature that would stand up to this highly saline environment. The stainless steel bearings were open. They were not sealed, nor were they lubricated bearings.

So after time the friction built up in this encoding drum, which you saw the photo of there, causing the whole system to hang up, or what we call step. The float, when rising and falling with the tide, did not generate enough work to turn the gauge to overcome the friction buildup in the gauge, and we had this stepping problem.

So our first action was to address that problem, and we did so by machining out the encoding drums slightly, which allowed a larger bearing to be put in. It was sealed prelubricated bearing, and, like I say, we have had no problems with that aspect of it since then.

The U.S. Geological Survey, like I say, has a lot of these gauges. They have not experienced the problem, nor have we experience the problem in the Great Lakes, which utilizes the Leupold Stevens gauge. We attribute our problem to the highly saline environment that we have tried to operate the gauge.

The Fischer Porter gauge -- we have modified the punch block, which has been a persistent problem giving fuzzy punches and all. We have modified that to allow for a much cleaner punch. It requires less force to punch the tape now through the modified punch block than it did before, so that's just one example.

The code hills on the code disc have been remachined, and in some cases actually chrome-plated. I think that will become a standard modification now, the chrome plating. What happens on the code hills, as the punch block goes in time and time again, it actually makes a little hole right there and causes the punch pin to not operate properly.

CDR FISHER: That may be a little more detailed than I was looking for.

MR. MASTERSON: I'm sorry.

CDR FISHER: I wanted to point out on the Fischer Porter -- the Leupold Stevens, I think, represents about 1976 on. Fischer Porter represents the early seventies, possibly late sixties on. That was off the shelf, too. What was that originally designed for?

MR. MASTERSON: I think that gauge was originally designed as a traffic counter. It would sense a signal as a car drove over it, and it punched the count out.

CDR. FISHER: So basically that mode was NOS was looking at off-the-shelf type equipment.

MR. MASTERSON: Right.

Any other questions?

CAPT WESLEY V. HULL, NOS, Officer of Oceanography: To explain a little further what Bob has been talking about and what Carl commented on, since the early days the NOS has made tide observations since about 1934. We have traced some of those observations back, such as San Francisco, for continuous records since about 1850, so we do have long experience in making tide observations.

A lot of the technology used in tide observation has been about a hundred years old. We traditionally use the standard tide gauge, which, again, was a float-type gauge, counterweights, pulleys, wires, and clocks that you wind up and a pencil that physically traced the rise and fall of the tide, a very efficient, a very accurate gauge.

However, when the requirement increased, it made it very difficult to take that analog record and process by hand, so therefore we started looking for something to go into automation. Around 1963 or 1964 is when the Fischer Porter ADR tide gauge came in.

As Bob mentioned, it was designed as a traffic counter. As we all drive down the road, you see the black hose across the road, you run over it, pressure punches. Without much engineering development, engineering management going into that, the ADR Fischer Porter came into inventory.

And because we are mentioning company names, we do not intend to either endorse or talk bad about those companies. We are speaking of gear that was available. We had a lot of problems with the Fischer Porter gauge, not only in getting spare parts, but getting spare parts that would work.

There are several things that have been developed that private industry did not develop. It was forced upon us to develop to get a gauge going. One was the timer that was mentioned. In 1975 we brought the first gauges of Leupold Stevens in, because the Fischer Porter was giving problems, and we went looking again.

The Geological Survey, the large thousands Bob mentioned -- there is about 13 to 14 thousand of those. Again, there was no engineering management that went into that tide gauge. We have about 349 of those Leupold Stevens gauges. When we went to having problems with those gauges after about a year in the field, we began looking.

And though a lot of effort and a lot of engineering design, redesign, test, and evaluation is the reason we have come up with all those modifications. We have instituted a data quality assurance, as Bob indicated, and on this next generation gauge that we will hear about shortly, we are looking at engineering management from the start.

The objective is to improve data quality in a cost-effective manner, so that has brought us up basically the history of where we were in the tide gauges, how we got to where we are.

We have approximately 1,000 total gauges in our inventory. The dollar figure hasn't been mentioned for the modification of these gauges. We are having to go on contract mostly to have the gauges modified at this time, but the dollar figure is about $600 to $800 per gauge. That basic instrument initially cost about $1500, so it is a major investment we are putting in here. We have got between 180 and 200 gauges modified at this time.

LT. W. DEWHURST, NOAA Ship WHITING: Bob, I think the system is good. I hope to be able to support it. It looks pretty immense to me. I have a couple of questions for you, though. The first, will the FAILogs be the instruments which will identify future problems and go into the development of the new generation tide gauges?

MR. MASTERSON: That will certainly be a part of our system evaluation, the FAILogs used in conjunction with the data defects that we are identifying from the raw data. Maybe Donny can address exactly how this information is going to be used in the procurement process of the next generation.

But to answer your question, yes, for sure it will be used, and not only in the procurement of the next generation system, but future improvements to the one we've got, because it is going to be some time before we get a new system out there in the field.

LT DEWHURST: Okay. You mentioned the field verification test every three months. I noticed there were certain instruments that were necessary in order to perform those tests.

MR. MASTERSON: That is right.

LT DEWHURST: Will those be provided to the field units and to the ships if it's necessary for them to provide those tests?

MR MASTERSON: That's correct. We are procuring those now. As a matter of fact, I think they just came in last week. If they are not, they are expected in any time.

LT DEWHURST: So the marine centers will provide to the ships, if I understand correctly, those instruments if it's necessary?

MR. MASTERSON: That's correct.

LT DEWHURST: I take it the ILSP is being used on both coasts with all field parties and ships?

MR. MASTERSON: Right, and our private contractors also.

Let me just comment on that. We have contracted with private surveying engineering firms for the operation and maintenance of many of our control stations, and those contractors are adhering to the ILSP.

LT DEWHURST: Okay. I noticed something in the slides, something that was missing, actually. I noticed a lot of four-inch wells and six-inch wells, but I don't think I saw any twelve-inch wells, the special fiber glass ones for the primary stations. Are those being used any more?

MR. MASTERSON: Oh, yeah. I was dealing with the subordinate stations, such as those that would be utilized by the hydro ships. But our control stations

typically have twelve-inch wells, and there is nothing to prohibit a hydro ship from putting in a twelve-inch well, but it's not a very easy thing to do in many cases. So the six- and four-inch wells are much more versatile.

LT DEWHURST: Okay. So those twelve-inch wells are still out in the field, and we will see those?

MR. MASTERSON: Oh, yes, very definitely.

LT DEWHURST: Thank you.

MR. DIXON: Thank you, Bob. Well done. I noticed some chuckling there. I hope because a few people are short on spare parts that we don't have a rash of Fischer Porter traffic counters torn up on the highways. (Laughter)

LAUNCH WIRE DRAG REFINEMENTS

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ABSTRACT. Some improvements to the launch wire drag system used aboard the WHITING for clearing obstructions are described. The importance of standardized record keeping is stressed and an example of an area and depth diagram produced by launch wire drag is presented. The effectiveness, efficiency, and magnitude of a launch wire drag operation are also discussed.

INTRODUCTION

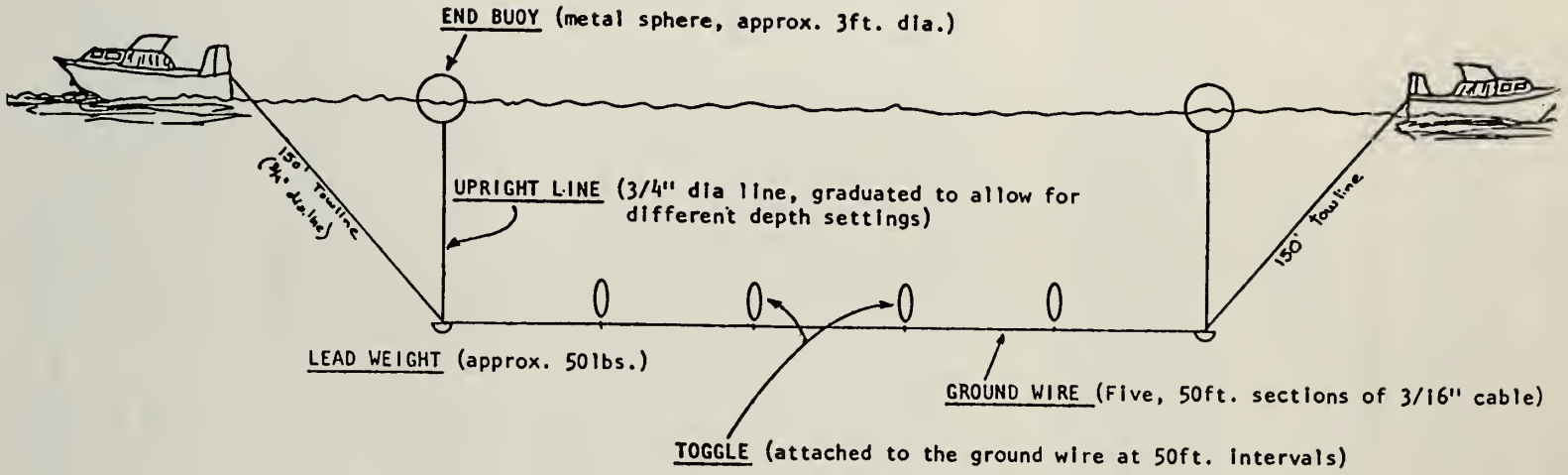
In recent years there has been a renewed interest in investigating the numerous wrecks, submerged pilings, rocks, and other obstructions which fall within the limits of a hydrographic survey. This interest is evident by the significance which project instructions place on item investigations. In fact, most project instructions for hydrographic surveys require that a thorough item investigation be conducted and specify that some method of improvised wire drag, sweep, or bottom trawl be used (NOS, 1979). The method selected must be operationally suited for the geographic area, bottom characteristics, currents, and other environmental conditions in which it is used. In areas where diving is not permitted, reliable least depths cannot be obtained, or an explicit requirement for a cleared depth exists, wire drag is usually the best method. Wire drag (with appropriate testing of the drag depth) is an accepted method for obtaining cleared depths on obstructions.

The problem of adapting or scaling down the NOAA Ships RUDE and HECK wire drag operation to something that is feasible for a hydrographic survey ship or hydrographic field party was addressed aboard the NOAA Ship WHITING (Ethridge, 1980). The launch wire drag system used on the WHITING is shown in figure 1. This system was designed to hang reported obstructions in areas where the bottom was strewn with debris not of charting significance. It was also designed to clear the obstructions once they had been located.

The survey data from the launch wire drag investigation of Item 3 in the New York Harbor Project has been processed by the Atlantic Marine Center (AMC) Verification Branch (NOS, 1980) and a number of system improvements have been recommended. Since most of the refinements are in the record keeping area, which was not addressed in the previous launch wire drag report published in the proceedings of last year's Hydrographic Survey Conference, it is appropriate that they be documented now.

FIGURE 1

LAUNCH WIRE DRAG GEAR, NOAA Ship WHITING


END BUOY (metal sphere, approx. 3ft. dia.)
150' Towline (¾" dia. line)
UPRIGHT LINE (3/4" dia line, graduated to allow for different depth settings)
150' Towline
LEAD WEIGHT (approx. 50lbs.)
GROUND WIRE (Five, 50ft. sections of 3/16" cable)
TOGGLE (attached to the ground wire at 50ft. intervals)

NOTE: All connections between adjoining sections of ground wire, ground wire and towline, upright line and ground wire, lead weights and ground wire, and toggles to ground wire should be made with shackles and swivels.

RECORD KEEPING

An important point to remember when recording any survey is that the final survey is only as good as the records which describe it and the data which supports it. Although the equipment and field procedures used for launch wire drag are improvised, the records and record keeping methods should not be. In fact, the record keeping should conform as closely as possible to that used for the standard wire drag. This not only makes the survey easier to process, but more professional and believable as well.

The following is a list of record keeping items applicable for a launch wire drag survey. See the Wire Drag Manual (Ulm, 1959) for more detail.

1. Record the data in wire drag volumes, which are specifically suited for this type of data.

2. Since wire drag surveys are processed separately from hydrographic surveys, list pertinent control information in the wire drag volume index.

3. Show all effective depth computations.

4. Show effective depth diagrams. There is a stamp to facilitate this.

5. Keep a wire drag diary or journal and briefly describe each strip. Include notes and descriptive information not shown in the wire drag volume.

6. Be sure to describe the bight of the drag (normal, straight, reverse, etc.)

7. The guide vessel wire drag volume should contain the data for both the guide and end vessel.

8. Record locality and sublocality in all volumes.

9. Use wire drag information stamps to record drag depth, section lengths, towline lengths, etc., for each strip.

10. Present wire drag convention stipulates that all positions and fix information be recorded in the wire drag volumes -- not on computer print out.

11. If automated data can be made to conform with existing wire drag programs, much time can be saved in processing.

12. All strips not rejected should be plotted and the end and guide vessels' paths should be identified.

13. Use of colors for different effective depths is sometimes useful.

14. Field area and depth sheets should be constructed as per the Wire Drag Manual.

15. If any data is rejected, be sure to explain why.

16. All lift tests should be properly recorded in the tester volume.

17. When plotting drag strips and compiling area and depth sheets, use the largest scale available which is commensurate with the method used to control the survey.

The above list can be summarized simply as "use standard wire drag record keeping procedures as per the Wire Drag Manual." Although this information is straightforward and available, it does represent an additional body of knowledge with which the hydrographer must be familiar in order to carry out an effective launch wire drag investigation.

FIELD PROCEDURE IMPROVEMENTS

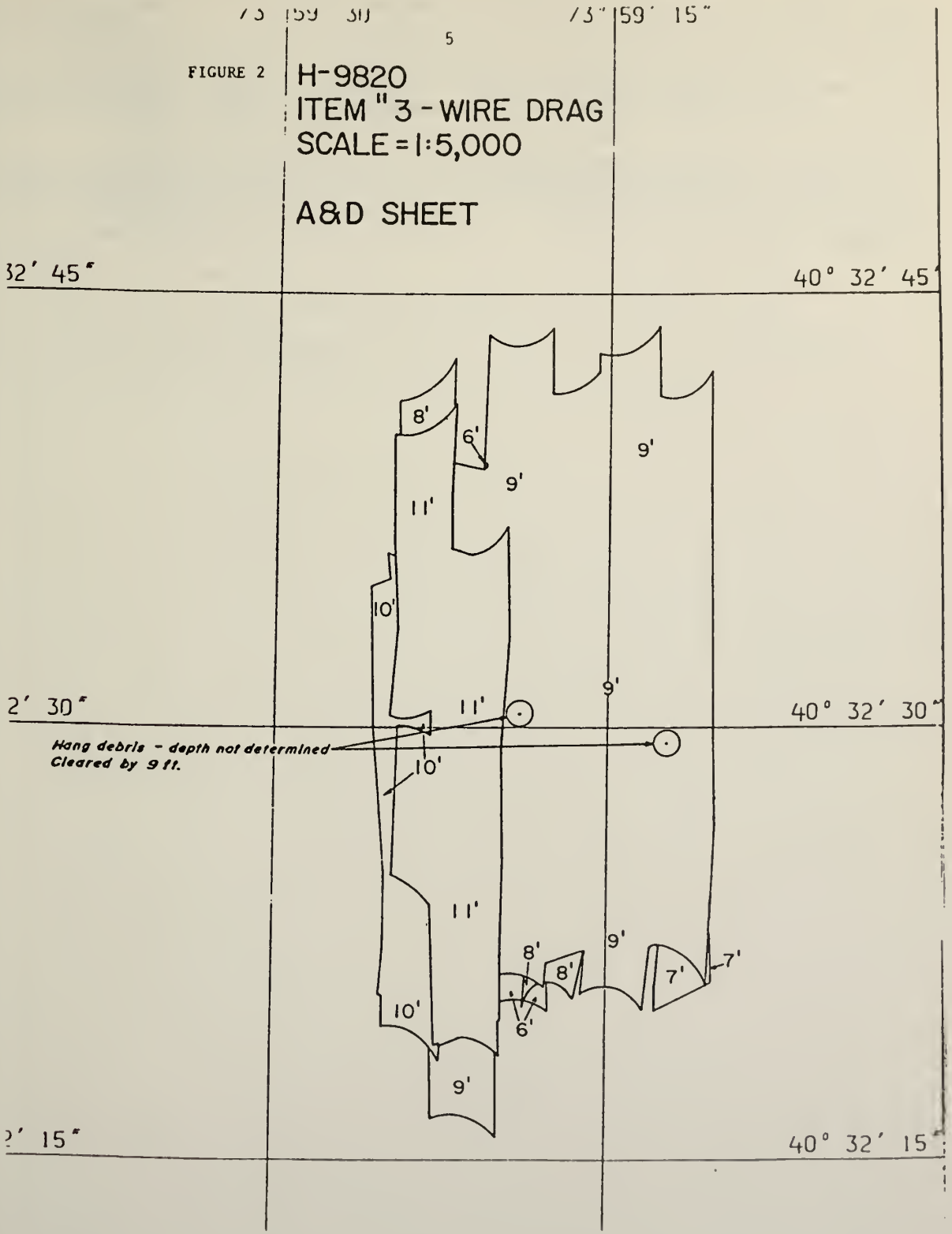
AMC processing and verification of Item 3 has also revealed some areas in the field procedures which could be improved. For example, if an intermediate buoy was added (and perhaps some more ground wire) to the scheme shown in figure 1, a more accurate determination of the behavior of the drag bight could be made. Also, at the time of each vessel fix, sextant cuts could be taken from each launch to the two end buoys. When plotted, these cuts will yield positions for the end buoys, and, together with the positions of the towing vessels, provide further information concerning the nature of the drag bight.

These additions to the equipment and procedures should serve to improve the system. However, their "field validity" or practicality will have to be proven with field experience.

CONCLUSIONS AND RECOMMENDATIONS

Figure 2 shows the area and depth diagram for Item 3 which was prepared by Maurice Hickson of the AMC Verification Branch. A wire drag area and depth diagram is a plot which shows the area that has been cleared and the maximum effective depth to which it was cleared. This diagram is evidence that the launch wire drag system described, when combined with proper record keeping, represents an effective method for clearing obstructions. More experience with this method will lead to further refinements and improvements which contribute to increased effectiveness.

Although this launch wire drag has been shown to be effective, it has not proven to be efficient. The field operation requires 10 men, 2 launches, and 1 skiff, and the processing and verification are done mostly by hand. This makes for a rather costly operation. For the specific example of Item 3, 160 man hours, 4 launch days, and 2 skiff days were used in field operations, 15 man hours in shipboard processing, and 100 man hours in the AMC Verification Branch . At current salary rates, this amounts to about $2,000 plus 4 launch days and 2 skiff days. Certainly somewhere in management a decision must be made concerning whether or not such investigations are worth what they cost.


73° 59' 30"
73° 59' 15"
5
FIGURE 2
H-9820
ITEM "3 - WIRE DRAG
SCALE = 1:5,000
A&D SHEET
32' 45"
40° 32' 45"
8'
6'
9'
9'
11'
10'
9'
2' 30"
11'
40° 32' 30"
Hang debris - depth not determined
Cleared by 9 ft.
10'
11'
8'
9'
8'
7'
7'
10'
6'
9'
2' 15"
40° 32' 15"

Due to the time and costs involved, it is recommended that launch wire drag be used only when there is no other acceptable technique available to do the job. In addition, survey planners must recognize the body of knowledge that has to be mastered, the skill and experience required, and the large amounts of time and equipment necessary in order to successfully execute a wire drag survey to clear an obstruction or disprove its existence. In effect, when such an effort is assigned to a hydrographic survey ship, one is requiring that a miniature RUDE and HECK operation complete with equipment and personnel skilled in both field wire drag procedures and wire drag record keeping be instituted aboard ship. Acceptable wire drag, with documented validity sufficient for clearing or disproving obstructions, is a highly specialized and sensitive operation.

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CONSTANT TENSION WIRE DRAG SYSTEM

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Abstract

The Constant Tension Wire Drag System was developed to investigate obstructions to navigation in confined areas with heavy traffic, strong currents and irregular bottom. It is a modification of the British Constant Tension Drift Sweep System, but differs from it in several features The system incorporates off-the-shelf commercially available equipment and can be used on existing 20- to 30-ft launches. The system was developed by the NOAA Ships RUDE and HECK during 1980.

Introduction

During OPR-B645-RU/HE-80, Wire Drag Item Investigations in New York Harbor conducted during the 1980 field season, it quickly became evident that the wire drag techniques normally used by the RUDE and HECK would not be effective. Because of heavy vessel traffic, strong currents, and restricted areas for maneuvering, it was impossible to wire drag with the RUDE and HECK in some cases and dangerous in others. A number of alternative methods of wire drag were evaluated before a decision was made to concentrate on a modification of the English Constant Tension Drift Sweep system. In its present form the English system consists of a horizontal wire suspended at a known depth below a vessel, or between two vessels. The wire is kept under a constant tension of approximately 20 lb by an Owens automatic tension winch. This winch is driven by a constant speed electric motor through a "fluid flywheel" clutch. The clutch may be preset at a desired tension and this tension will be maintained on the wire. The system is used in a drift configuration with the vessel or vessels being carried over the bottom by the current and wind.

The RUDE and HECK system differs significantly from the English System in several respects. First, a 650-lb test Kevlar™ (a recently developed lightweight, high strength aramid fiber) line is used instead of 1/32-inch diameter piano wire. Second, a heavy duty commercially available fishing reel, equipped with an electric motor, is used in place of the Owens automatic tension winch. And third, the RUDE and HECK system is normally used with the launches under power, which allows the use of the RUDE and HECK system under more widely varying conditions of current and wind. This is a necessity, since we use the system not only to find the least depth of the obstruction, but also to search for the obstruction.

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At this point it should be noted that the Constant Tension System should not be used indiscriminantly. This system is extremely expensive in terms of cost per unit of area covered. In addition to operating at a very low speed, it requires seven or eight men, two launches, and one skiff. Verification of the acquired data is also a difficult and time consuming procedure. While on the subject of verification, I must stress the need for adequate documentation. No matter how much effort is expended in data acquisition, lack of adequate documentation of the procedures used, and therefore lack of proof of the use of proper procedures, may result in the rejection of good data.

System Design and Rigging

The RUDE and HECK Constant Tension Drag System is simple in concept and consists of a relatively few, readily obtained components which can be added to existing 20- to 30-ft launches. The primary components of this system are:

1. Two davits which can be designed and fabricated to fit the individual needs of any particular launch.

2. 1/8-inch stainless steel wire from which the end weights are suspended.

3. Two streamlined 80- to 100-lb end weights.

4. Two boat trailer winches for lowering and raising the end weights.

5. One electrically powered heavy duty fishing reel to maintain tension on the sweep line.

6. 650-lb Kevlar™ line to use for the sweep line.

7. Various small blocks, flanges, and snap hooks, all of which will be enumerated in the list of materials at the end of this paper.

8. One 14- to 16-ft outboard powered skiff.

9. One wire drag tester.

Figure 1 shows two small launches fitted with the basic launch drag equipment. Each launch is equipped in the following manner: The davit with its attached winch is mounted in the launch at a convenient place to allow for easy cranking of the winch and also to insure that the weight can be put over and brought aboard easily and safely. The winch carries about 100 ft of 1/8-inch stainless steel wire marked as documented in the Wire Drag Manual (Ulm, 1959).

In the guide vessel, the upright wire is passed through a block on the davit and shackled directly to the staple at the top of the end weight. The pneumatic depth gage hose is attached to the staple on the side of the weight via a snap hook which has been seized tightly to the end of the hose. The other end of the pneumatic depth gage hose is attached to the gage in the guide vessel.

The upright wire for the end vessel is passed through a block on the davit and shackled to the end weight in exactly the same manner as with the guide vessel. The sweep line from the electrically powered heavy duty fishing reel is passed through a second block on the end vessel's davit, through a block attached to the staple in the side of the streamlined weight, and is then attached to the staple in the side of the guide vessel's end weight by a snap hook. If tension is kept on the sweep line there will be no tendency for the end weight to rotate and thus foul the sweep line. If desired, a second pneumatic depth gage can be rigged on the end vessel in the same manner as on the guide vessel to monitor the depth of the end vessel's weight at all times during the drag.

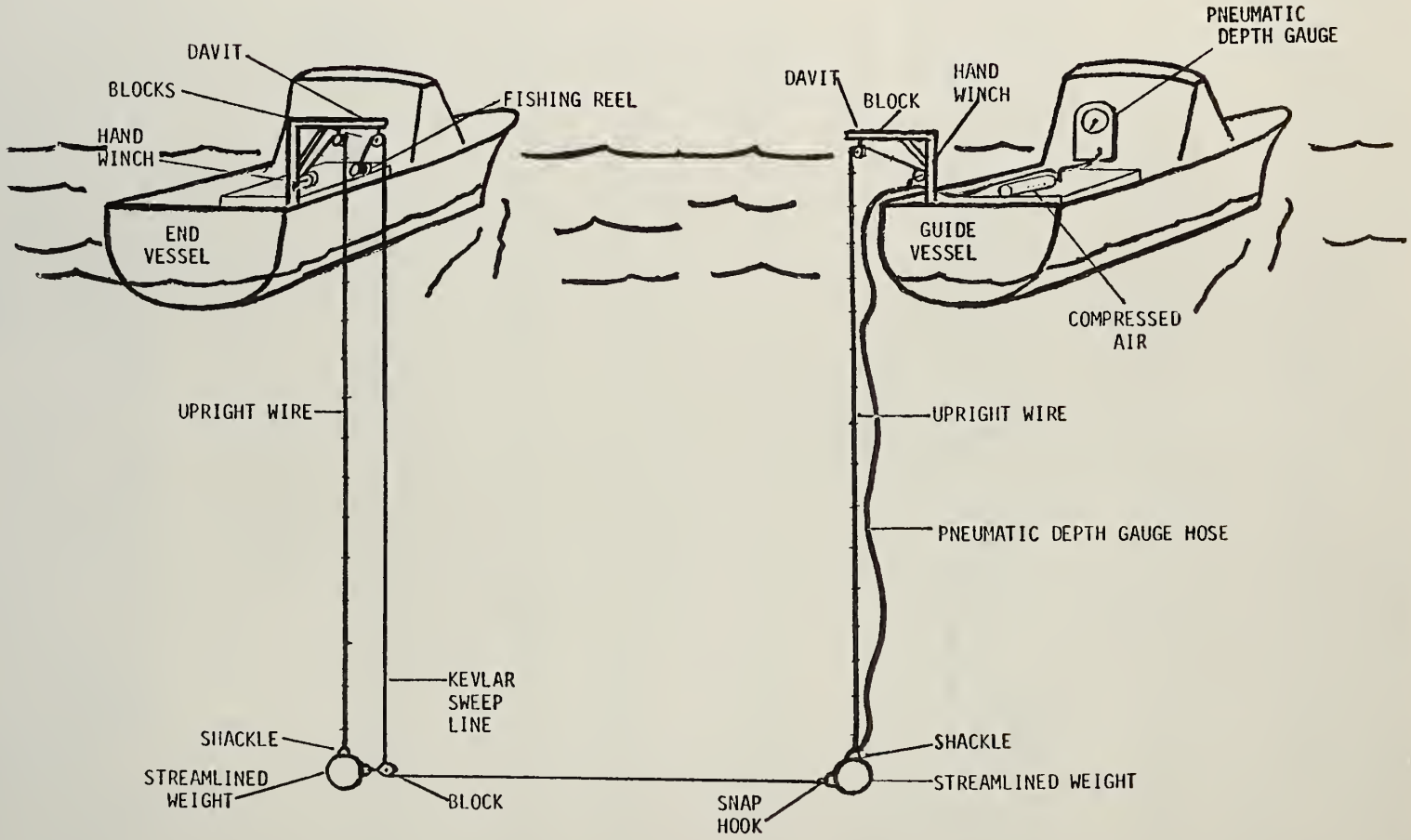


FIGURE 1

CONSTANT TENSION WIRE DRAG SYSTEM SET-UP

Method of Operation

The launch drags should be set up to take advantage of the current. The drags should be run with the current at as slow a speed as possible to minimize the lifting tendency of the end weights as they pass through the water.

Since the RUDE and HECK launches do not have computers, artificial ranges utilizing buoys with lines of short scope are set up to insure accurate navigation of the launches. These buoys can be positioned by either electronic or visual techniques. A separate range for each launch can be set up. Alternatively, only one range is set up and the guide vessel navigates this range. The end vessel maintains station on the guide vessel by observing the markings on the sweep line as it unwinds from the reel. The second method decreases set-up time considerably, but requires closer attention and greater skill on the part of the coxswain of the end vessel.

After the ranges (or range) have (has) been set up, the launches are run to a point upstream of the beginning of the drag area. If two ranges are used the launches position themselves between the ranges and pass the sweep line from the end vessel to the guide vessel. After the sweep line is attached to the guide vessel's end weight by a snap hook, each vessel slowly proceeds to its respective range while keeping tension on the sweep line and lowering the end weights to about 4 feet above the desired drag depth. The vessels then turn on range and maneuver until they are abreast, and start down the range at slow speed. The weights are then lowered to the desired drag depth (plus 1-2 feet for expected lifts and whatever additional depth is necessary for predicted tides) and the drag begins. Each minute the following data is recorded:

1. Position information.

2. Depth from pneumatic depth gage.

3. Launch speed.

In addition, the sweep line depth in the middle of the drag should be tested as often as possible with the drag tester (see section on equipment). The launches should be operated at a slow speed (2-3 kts through the water) and the coxswains should be cautioned to make all maneuvers as slowly and smoothly as possible to avoid momentary, excessive lifts of the end weights. After the drag is completed, the weights should be raised, the sweep line disconnected and new ranges set out if necessary. If a hang occurs, both vessels should immediately stop. The end vessel should then raise its end weight until the sweep line can be seen and backtrack along the sweep line until the sweep line is vertical. The position of the end vessel can be recorded--this should be the approximate position of the hang. Care must be taken when maneuvering the launch to prevent the sweep line slipping off the hang. After the line is freed

from the hang, the guide vessel's weight can be raised and the sweep line disconnected in preparation for another drag. If only one range is to be used, set-out is made in the same manner except that the guide vessel lines up on the range and the end vessel positions itself at the desired distance from the guide vessel prior to the drag beginning. This distance may be maintained by observing the action of the sweep line on the reel.

Theory

To insure that an area is cleared to a desired depth, the hydrographer must know the following facts:

1. The position of both vessels.

2. The effective depth of the line.

Dual vessel control should be used for positioning the vessels in all cases, i.e., each vessel should obtain its position at each fix. Either visual or electronic control may be used. Boatsheets of 1:5,000 scale or larger should be used with this system to insure that errors of plotting will be small compared with the width of the drag. International accuracy standards for hydrographic surveys specify the spacing of position fixes on the survey sheets to be from 2-4 cm (1-1.5 inches) (Umbach, 1976, 1.1.2, Section V). During the 1980 field season, fixes were taken at 1-minute intervals on sheets of 1:5,000 scale. At the slow speeds at which the launch drags are conducted, this caused much closer spacing than 1½ inches at survey scale and insured that adequate control was available, even if positioning data for individual fixes was missed or recorded incorrectly. Since the RUDE and HECK launches are not automated (no onboard computer) and lack facilities for manually plotting aboard the launches, all drags were manually plotted after the fact. If it is possible to plot in real time either manually or by computer, then it may be possible to run the drags without setting up artificial ranges.

To determine the effective depth of the drag, two facts must be known: (1) the depth of the end weights and (2) the behavior of the line between the two weights -- whether it is sagging or lifting. The depth of the end weight must be measured since, when the launch is underway, water resistance and the tension of the line will pull the upright wire out of the vertical plane. This can be done directly by one of two methods: (1) pneumatic depth gage or (2) electronic echo sounder. The RUDE and HECK used a pneumatic depth gage exclusively. (The design and use of the pneumatic depth gage is covered in the equipment list.) An electronic echo sounder may be used by rigging the transducer to the top of the weight in such a way that the transducer looks upward. The echoes will then be received from the surface of the water and the depth of the weight indicated directly on recorders carried in the boats. The second fact needed--the behavior of the line--may be determined by the use of a drag tester. Using this two measurement approach, it is reasonable to assume that the "worst case" lift condition has been detected and applied.

All constant tension drags were run with a 1-minute fix interval. At each fix, the depth of one end of the line was measured using a Roylyn 3-D precision depth gage configured as a pneumatic depth gage. The orifice of the pneumatic depth was attached to the weight at the same point that the line was attached. Lift was determined by subtracting the depth of the pneumatic depth gage from the length of the upright. This depth was recorded in the drag volume.

Lift at random points along the line was determined by use of a drag tester in the standard manner. This tester consisted of a ring buoy, a small winch, 1/8-inch flagged stainless steel wire and 1/2-inch diameter pipe covered with white lead. The wire is set to the desired test depth and the tester is placed in the water ahead of the drag. As the drag passed the tester the sweep line scraped the white lead off the pipe. The results of these lift tests were recorded on a rough tester sheet, reduced to actual wire depth, and entered into the drag volume. No smooth tester record was maintained for the single-section constant-tension drags.

The worst case lift was evaluated by comparing the results and times of both sets of lift tests and applying the greatest lift over the entire time period for which it was effective. In most cases, the controlling lift was that measured by the pneumatic depth gage. The controlling lift was applied to the upright length to the nearest one-half foot increment as is the normal practice.

Normally, launch drags of up to 400 ft may be made with the RUDE and HECK Constant Tension System. Beyond 400 ft the sag in the sweep line may become excessive. The sag in the sweep line (under static conditions) may be calculated by the following formula:

$$\text{Sag (in feet)} = \frac{\text{Weight of line (in water) per foot} \times (\text{length in ft})^2}{8\ (\text{tension in wire in lb})}$$

Therefore, for a drag of 300 ft in length (the length used most often by the RUDE and HECK) and 650-lb test Kevlar™ with 20 lb of tension, the anticipated sag (under static conditions) would be:

$$\text{Sag} = \frac{0.00031 \times 300^2}{8(20)}$$

650-lb test Kelvar™ weighs 1.35-lbs per 1000 ft in air (specific gravity of 1.3)

$$= \frac{0.00031 \times 90000}{160}$$

$$= 0.2 \text{ feet}$$

Unfortunately, the above formula is accurate only under static conditions (when the line is not moving relative to the water). Under a dynamic (or drag) situation, when the line is moving through the water,

the line may behave in a different manner. This would occur because of the water resistance encountered by the line being pulled through the water. In addition, different currents may exist at different points along the sweep line. Based on our practical experience with the system, the middle of the sweep line usually sagged by approximately 1 foot from the depth of the end weight. However, in certain cases, the line may actually lift above the level of the end weights. This occurs rarely, but necessitates the use of the drag tester to insure that an erroneous effective depth is not claimed.

Processing

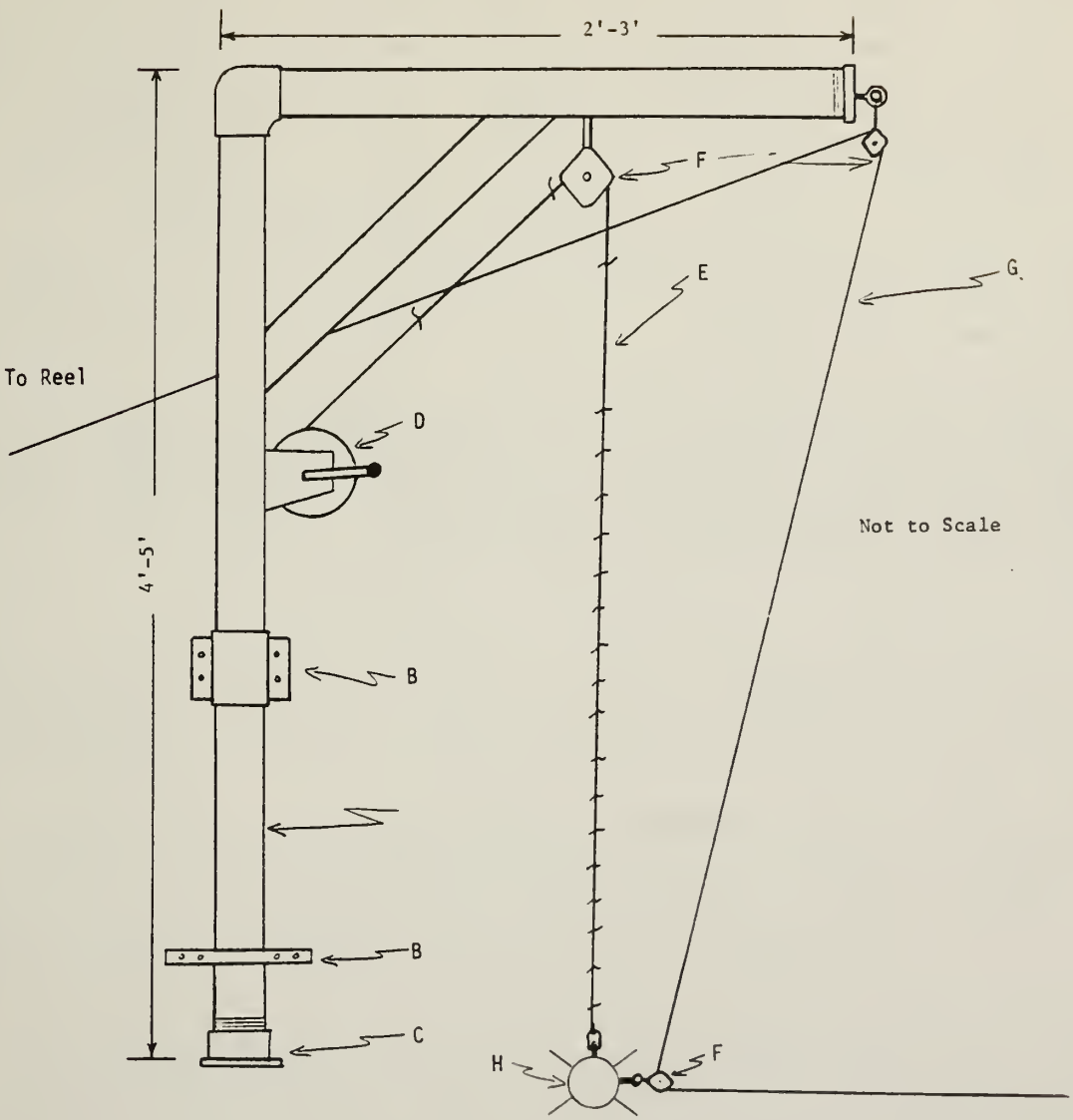
As with all data acquistion systems, the quality of the end product is only as good as the quality of the documentation procedures. Therefore, the procedures, stamps, notes, etc., recommended by the Wire Drag Manual (Ulm, 1959) should be used, and the data logged in Form 411, the USC & GS Wire Drag Volume. The position plot only option of the Hydroplot System can be used to plot overlays for each individual drag. These overlays can then be combined to produce an A and D (Area and Depth) sheet and to check for proper overlap. An overlap of 10 meters between adjacent drags should be adequate to insure that no holidays exist.

Equipment List

Launches: Any solidly constructed, stable vessel of 20 to 30 ft may be used as a drag vessel. The primary requirements are (1) that it can run at speeds of about 2 knots and that it be controllable at this slow speed, (2) that it be stable enough to support a davit with a weight of approximately 100 pounds hung over the side, and (3) that it be large enough to contain all the equipment and personnel and that the personnel not be too crowded to work safely.

Davits: The davits used by the RUDE and HECK launches were constructed of 2-inch galvanized pipe by shipboard personnel. Design details and approximate dimensions are shown in figure 2. The davit should be modified for the launch on which it will be carried. The davits on the RUDE and HECK launches bent slightly while in use with an end weight of 135 pounds. While this did not hamper operations, improved design and the use of a lighter end weight should be considered. Since the davit projects over the side of the launch, it is necessary, for safety, that the davit be designed so that it can be easily removed or rotated inboard when the launch comes alongside the ship. This can be done by securing a 2-inch threaded flange to the deck and partially threading the davit into the flange,allowing the davit to be rotated while still being held securely to the deck. The davit should also be securely mounted to the hull of the launch.

A small winch for raising and lowering the upright wire and a block through which the upright wire is led are attached to the davit. The end vessel also has a second, smaller block attached to the davit through which the sweep line is led.



A. Davit
B. Davit Support
C. Threaded Flange
D. Winch
E. Upright Wire
F. Blocks
G. Sweep Line
H. Streamlined Weight

Figure 2
END VESSEL DAVIT

Sweep Line: The selection of the proper sweep line (or wire) to be used with the Constant Tension System is very important. The line (or wire) must be strong enough so that it will not part on a hang, but it must also be light enough so that it will not sag excessively while in the water. The British Drift Sweep System uses piano wire. Although the wire is relatively light because of its small diameter, it is not strong enough to use when the vessels are operating under power. A number of alternates were evaluated before settling on the present choice, a relatively new aramid fiber, Kevlar™. This fiber is approximately the same strength as stainless steel, per diameter, but it is only about 20-25 percent of the weight. Both jacketed and unjacketed Kevlar™ in a variety of strengths are available. The unjacketed line with a strength of 650 lb was found to be the most satisfactory.

End Weights: Although the RUDE and HECK used three of their 45-lb intermediate weights shackled together to form a single end weight, a more satisfactory solution would be the use of a streamlined end weight. Such a weight should weigh between 80 and 100 lb and be equipped with two staples to be used as attachment points. (See figure 3.)

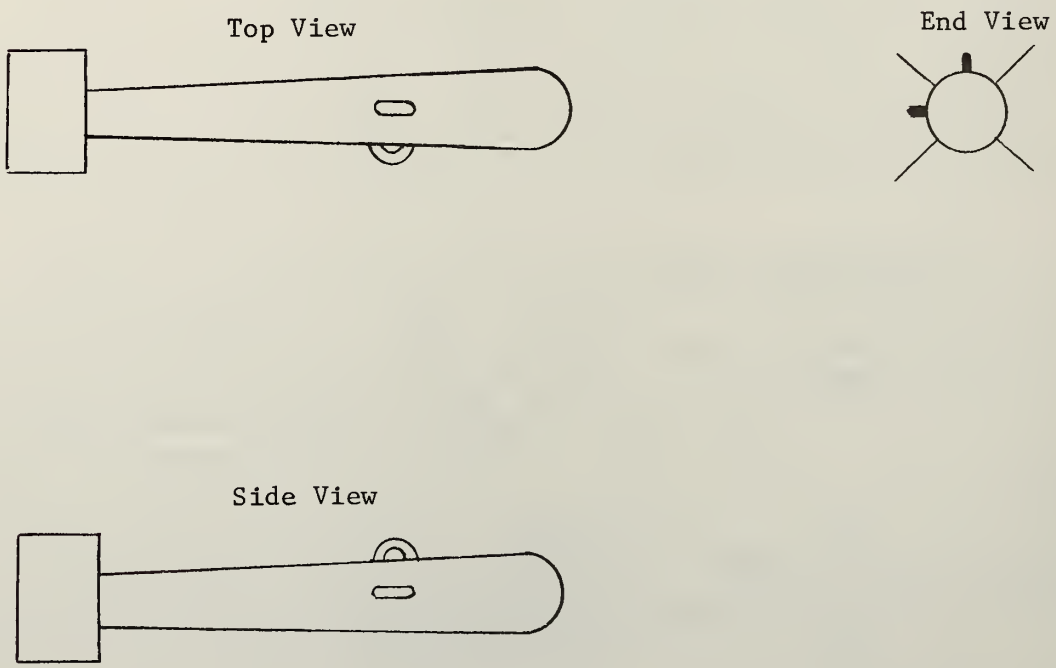


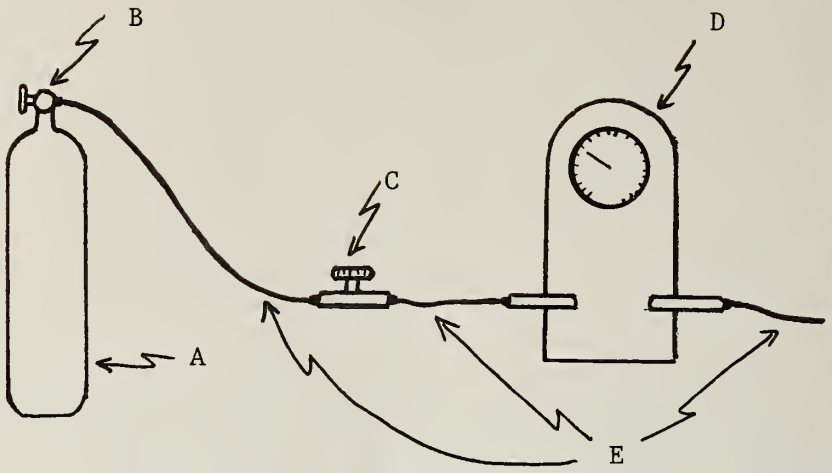
Figure 3
STREAMLINED END WEIGHT

Constant Tension Reels: Because of the decision to use commercially available components, no attempt was made to obtain and test the Owens Constant Tension Winch developed and used by the British. Based on observations made during the James River project in 1977, the Owens Winch appears to be much superior to the reels used by the RUDE and HECK this season. Although any motorized heavy-duty fishing reel could probably be used, the RUDE and HECK had their best success with a Penn 12/0 (model 116) heavy-duty trolling reel used in conjunction with an Elec-Tra-Mate™ Hawaiian Power Unit. Since the system put greater strains on the power unit than it was designed for, the 12-V electric motor is likely to burn out after several days of use. A spare motor should be kept on hand. In addition, several full sets of drag washers for the reel should be maintained. An Elec-Tra-Mate™ Pro 2000 was also tested since it had a much larger, more powerful motor than the Hawaiian. However, substantial modification would have to be made before it would be usable. An alternative to the use of an electrically powered reel would be the use a manual reel, a Penn Fatho-master™ 600 or equivalent. This unit has a large, heavy-duty drag system and can be used to maintain a tension of 15-20 lb by slow cranking. There are three disadvantages to the use of the Fatho-master™ 600. First, it has a capacity of only 450 to 500 ft of 650-lb Kevlar™ line. Second, a small spring in the ratchet mechanism of the reel is prone to break, although the spring is easily replaced. And third, a person must be assigned to maintain proper tension in the line by manually cranking the reel. The Fatho-master™, however, is more reliable than the electrically powered reel and can be used as a backup or as the prime reel if relatively little drag work is to be done.

Pneumatic Depth Gage: The pneumatic depth gage, which is used to monitor the depth of the end weights, is made from a precision depth gage, a scuba tank complete with the first stage of a scuba regulator, a high-quality needle valve and about 100 ft of small diameter tubing complete with oxygen fittings for attachment to the gage and needle valve.

The depth gage used by the RUDE and HECK was a Roylyn Model 25546-23B14 for which the manufacturer's specification of accuracy was of 1/4 of 1 percent over the gage's range of 230 ft (or about 0.58 ft). The gage should be calibrated by lead line both before and after the project, and the results entered into the field records. The pneumatic depth gage is used by opening the needle valve to allow an overpressure of air from the scuba tank through the system. The valve is then closed, the air pressure allowed to equalize with the water pressure, and the depth read directly off the precision depth gage. (See figure 4.)

Wire Drag Tester: The wire drag tester used was the standard configuration as shown in the Wire Drag Manual (Ulm, 1959) except built to smaller dimensions. See the list of materials for elaboration.



A. Scuba Tank

B. First Stage of Scuba Regulator

C. Needle Valve

D. Precision Depth Gage

E. High Pressure Oxygen Hose

Figure 4

PNEUMATIC DEPTH GAGE

List of Materials

Davits:

20 ft of 2-inch galvanized pipe
2 small boat trailer type winches (should be capable of holding approximately 100 ft of 1/8-inch wire)
200 ft of 1/8-inch stainless steel wire
2 blocks for 1/8-inch wire
2 blocks for 650-lb Kevlar™ line (sheaves should be enclosed to prevent the line from fouling between the sheave and the case of the block)
2 @ 90° bend elbows for 2-inch galvanized pipe
2 end caps for 2-inch galvanized pipe
1 ft of 2½-inch galvanized pipe (to be as supports for the davits)
2 2-inch threaded flanges
2 bronze snap hooks (Perko or equivalent)

Streamlined Weights:

2 @ 80- to 100-lb streamlined end weights with staples. (See figure 3.)

Constant Tension Reel:

1 Penn 12/0 (Model 116) heavy-duty trolling reel or equivalent (a larger size reel may be used if desired)
1 Elec-Tra-Mate™ Hawaiian Power Unit or equivalent
1 12-V motor for power unit (spare)
3 complete sets of drag washers for Penn Model 116 reel
1 Fatho-master™ 600 or equivalent. (This unit may be used in lieu of the above units if the drag area is small.)
3 replacement springs for the Fatho-master™ 600 (may be obtained at any hardware store, but may have to be modified to fit the reel)

Pneumatic Depth Gage:

1 Roylyn Model 25546-23B14 precision depth gage or equivalent
1 72- or 80-cubic-foot scuba tank
1 first stage of scuba regulator
1 needle valve
100 ft of high-pressure oxygen hose plus fittings

Sweep Line:

2,000 ft (minimum) of 650-lb test unjacketed Kevlar™ line or equivalent. Each length of line (about 600 ft) can be used for several days of dragging before replacement is necessary.

Wire Drag Tester:

1 30-inch diameter ring buoy
1 small ratcheted winch
100 ft of 1/8-inch stainless steel wire
1 6-ft long, 1/2-inch diameter pipe with 1/8-inch holes drilled at 1-ft intervals
1 small piece of exterior plywood used to attach the winch to the ring buoy
White lead and linseed oil used to coat the tester pole

Wire Drag Manual (Publication 20-1)

Wire Drag Volume(s) (Form 411)

Suppliers

Penn Reels
Penn Fishing Tackle Mfg. Co.
3028 W. Huntington Avenue
Philadelphia, PA 19132

Kevlar™ Line
Cortland Line Co.
P. O. Box 1362
Cortland, NY 13045
ATTN: Mr. John Dower (Marketing Sales Manager)

Elec-Tra-Mate™ Power Units
Electric Fishing Reel Systems, Inc.
Greensboro, NC 27420

References:

Ulm, K. S., 1959: Wire Drag Manual, USC&GS Publication No. 20-1, U.S. Department of Commerce, Washington, D.C., 103 pp.

Umbach, M. J., 1976: Hydrographic Manual, Fourth Edition, U.S. Government Printing Office, Washington, D.C.(Stock No.0-219-433), 330 pp.

CDR GRUNTHAL: That's all I have.

Do you have any questions that you would like to address to either Max or myself.

CDR CARL FISHER, Chief, Operations Division, AMC: I actually would like to make a couple of observations if I might, and they are very positive in note. And I think that when we get our next presentation, that presentation will lend some input to what I was going to make, and that is that there are a couple of evolutions taking place here, and one thing is a real strong point I want to make about the input to the hydrographic conferences.

The first evolution is the extent to which hydrographic units are beginning to use this technique, and a little comment on that is -- and it's interesting in this period of high technology, what we have been looking at for the past couple of days -- and that is that the hydrographer, when doing a survey, views his responsibility on proving, disproving these items, and we use both Presurvey Review Items, and investigation items -- that he has the responsibility to do that, and he uses what techniques he can obtain to do it.

So even though it may be labor-intensive, even though it may involve quite a bit of innovation, the field hydrographer is doing that. I think that the program area views this because, as we have grown in this development, the program area has grown in the, I guess you might say, development of the requirements in the project constructions and also in the data handling, so we have an evolution going on there.

The responsibility was always there. It's just kind of -- I would say more time is being spent per item. We are investing more in that aspect.

Now, the second evolution I want to point out is one that relates directly to these conferences, and I view back to, say, '78, and that is that we have had a number of papers on this topic. We have heard from a number of ships, one of the reasons being that as this responsibility is laid on, those units have begun developing, which I think is very constructive.

We had one effort prior to that conference, which would be the NOAA Ship DAVIDSON reporting on techniques that they used with outerboards. We have had reports from the NOAA Ship PEIRCE, the NOAA Ship WHITING, a couple of reports from the NOAA Ships RUDE and HECK. I believe there was a paper given on techniques used in the Great Lakes prior to this effort. So we have heard quite a few times, and I think that's quite valuable because the units are going out there each year doing their best, innovating, and coming back and reporting to us.

However, if I do go back to "78, I do raise one question, and that is that there was a request made, a recommendation, and that being that foreseeing all this individual development in the field, that there be some coordination of the effort. And some look at the technology.

You commented earlier on the innovation of transducers on the actual weights. There are many ideas that could be thought of, and I myself propose that we haven't given sufficient attention to this, for what it represents, the percentage of a survey. And I could take off the top of my head, 25 percent. Some surveys in areas that have numerous items like this, it may even go quite a bit higher, that for the amount that's being invested in that, I myself feel that there should be a coordination.

This year we haven't heard from the West Coast, but my impression is that there must be innovation out there, too, and the thrust of some of what Max said earlier, and you said, is that we have certain bounds that we innovate within. We don't want to innovate to where we destroy the credibility of the data, so we need the coordination both to lend support, see that we are all going in the right direction, and at the same time don't do anything to destroy its credibility.

And that's just a general comment that I wanted to get into the proceedings of this, to see if, once again, over two years later, make the request that this be given a higher priority. I think in the wisdom of the years, rather than tasking a development area to go ahead, it's probably been quite wise to let our field units experiment and develop and grow. But after a couple of years of this, I think maybe we need to take a second look and see if we can proceed from here. Thank you.

CDR GRUNTHAL: Thank you, Carl.

LUNCHEON PROGRAM

CDR KIENINGER: Ladies and gentlemen, may I introduce to you Rear Admiral Richard Houlder, who is the Director of the Atlantic Marine Center.

Admiral Houlder?

RADM HOULDER: I would just like to welcome all of you to our session down here. It's your participation that really makes these meetings worthwhile, and from what I have seen so far, it has been very satisfying on the part of all the people who have worked at AMC to put on this conference and meetings with the Canadians and all.

I would like to introduce just a few people. First, I would like to introduce Admiral Munson, who I am sure most of you are very familiar with, having been director down here, and who is now in the Office of Marine Operations.

Admiral Munson?

You don't have to clap.

(Laughter)

Next I would Ike to introduce a friend and associate from Canada, Mr. Tom McCulloch, who is the Director General in the Central Region of Ocean Sciences and Surveys Activities, and I would like to give Tom a chance, if he would like, to say a few words.

MR. CcCULLOCH: Thank you, Admiral Houlder. I know Steve, our Dominion Hydrographer, is going to do the honors on behalf of the Canadian contingent, but I thought I would like to get my oar in here while I had an opportunity.

First of all, we thank Admiral Lippold and Admiral Houlder for having us here, but also to do a little bit of propaganda on behalf -- I'm putting another hat on now. I'm the chairman of the commission for the Hydrographic Commission of the International Federation of Surveyors, and that commission is the voice of hydrography. I believe IHO does a good job, and to make sure we are doing a good job, we have quite a few powerful people on our team, including Admiral Munson, who is the executive secretary of that commission.

To those of you who are not aware of the organization, the ACSM is your entree into FIG, the International Federation of Surveyors, which are having a Congress in Montreux, Switzerland, in August of this year. We are going to be hopefully talking a lot about what's going to happen when the Law of the Sea thing is finally decided, the exclusive economic zones, et cetera. We are hoping for a large participation from the Third World, but most of all we are hoping for a large participation from North America. So I invite you all to come and join us in Montreux, Switzerland. It's a great place.

(Applause)

ADMIRAL HOULDER: Thank you, Tom. Unfortunately, our travel restraints may put some restrictions on that.

Next I would like to introduce the Canadian Dominion Hydrographer who we are honored to have with us this week, Mr. Steve MacPhee.

MR. MACPHEE: Thank you, Dick. It's indeed a pleasure today to be able to address this august group of North American hydrographers and to say a few words on the occasion of your 1981 NOS conference and on the occasion of the fourth meeting of the Canada/USA Charting Commission.

I was most impressed, since I arrived here, by the quality of the papers. It is a most interesting conference, and all the Canadians, and I'm sure all the other delegates, are very, very pleased with the way the conference has progressed today.

I could discuss a number of topics, but I think I will just zero in on one topic, and that is the spirit of cooperation that has existed between the Canadian Hydrographic Service and the National Ocean Survey. Over the years we have had quite a number of areas of interest, and we have had areas of agreement and areas of disagreement.

I guess our greatest agreement and our greatest success has been in the area of cooperative surveys, chart scheming, and in the exchange of personnel. We have had areas of disagreement, but in our areas of disagreement, we have always been able to express our opinions, and we have always been able to communicate, and while this dialogue continues -- and I see no reason why it should not continue -- then we will have much success in the future.

On behalf of the Canadian delegation, I thank you kindly. I congratulate the conference committee on the splendid work you have done, and I wish you the greatest luck in future conventions. Thank you very much.

(Applause)

RADM HOULDER: Thank you, Steve.

The next item I have on the agenda is the introduction of the main speaker today. We have a volunteer from Canada to introduce our speaker, so at this time I would like to introduce Mr. Michael Bolton, Regional Hydrographer, Victoria.

MR. BOLTON: I really thought he was kidding. However, ladies and gentlemen, distinguished delegates, guests, friends, it is my honor, privilege, and pleasure to present to you a gentleman who I think needs no introduction. However, I will try. Unfortunately, I do not have his biography here, but he told me last night he is the most distinguished man who has ever worked for this august body. Who am I to argue?

So without saying any more, may I introduce to you, Admiral Herb Lippold, Jr., Director of the National Ocean Survey. Rear Admiral Lippold?

(Applause)

RADM LIPPOLD: I would like to wish everyone a belated welcome, especially our Canadian friends and other U.S. Agency participants. I regret I could not be here for the opening.

I would like to treat the few words I plan to say similarly to a note that was attached to a speech authorization for this conference that came up to my office a couple of days ago:

"Author has no prepared paper at this time; he will give the speech from notes. The paper to be published in the proceedings will be written after the conference to allow the incorporation of up-to-the-minute developments in this rapidly developing field..."

Over the last decade, I have heard many times that hydrography is a dying profession; we are losing our expertise; our surveys are going downhill; our equipment is inadequate; it is technician work; and, we are falling behind requirements farther and farther each year.

I don't believe it!

Our waters are surveyed better today than they have ever been before. In fact, NACOA and some others in our country have the idea that we are resurveying for the sake of resurveying. I say wrong again!

We are doing good work. Our ships are modern hydrographic platforms. Our surveys are more accurate than they have ever been before. Our positioning systems are the best in the world.

Overall, our data acquisition, processing, and compilation systems are superior to anything we have ever had before. Our specifications, procedures, and standards are excellent.

We have lost much talent, which is difficult to replace and develop, but have you ever seen such capable young people as we have coming along today. They are the ones responsible for the systems we now have and are moving ahead to make them better.

We have a very effective working hydrographer's school at PMC. We are involved with the U.S. Navy in a graduate school established at Monterey. We are exchanging cartographers with the Canadian Hydrographic Service and other people at the marine center level. We have started an exchange hydrographer program with Great Britain.

And the best part of it all is that we are talking to each other, "comparing notes" you might say, working together to get the most done for the dollar, eliminating duplication, working toward common goals and standards.

I look at all of you here working toward these common goals. Have we ever had such a united effort?

My answer is NO.

Now, it isn't all "peaches and cream."

We have to continually move ahead to put out more accurate and timely products.

Once you "bite the bullet" and go into automation, these machines become "monsters" requiring constant maintenance and upgrading, software modifications, often becoming obsolete before they are fully operational, and continually increasing replacement costs. It's like having a bear by the tail.

In some cases, the process is more labor intensive than before. Our hydroplot system is an example. We are bound up in shipboard processing that has limited our Class II production.

The continual reduction in personnel ceiling forces us to move ahead as fast as possible in the automated mode, therefore committing a continual flow of dollars for hardware and software.

Our second generation Hydroplot must be developed before the present system becomes so troublesome that efficiency goes down the drain.

New, more efficient types of acquisition systems must be developed and put into use; such as laser and swath systems.

We must begin a comprehensive bathymetric data acquisition program for accurate maps of the ocean bottom.

I could go on and on, but I think we all realize what is ahead of us and <u>that</u> is the first positive step.

With the excellent coordination and cooperation that you have brought about today, nationally and internationally, how can we miss. This is just the type of forum to set our course more definitively for the future and resolve common problems.

Ladies and gentlemen, I salute you for the mighty effort you are making toward the future and with this type of dedication, how can we miss. Thank you.

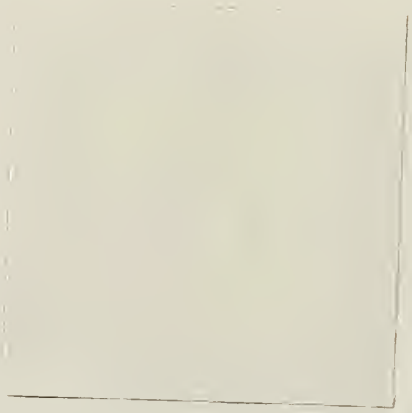
(Applause)

RADM HOULDER: I thank you, Herb, and all the people here.

One thing before we close the formal part of this is I would like to express my appreciation to all the people in the Atlantic Marine Center that have worked so hard to put on this conference and the associated meetings, and I would just

like to ask that all the AMC people stand up, because I think they deserve a round of applause.

(Applause)



DIVER UNDERWATER SURVEY AND OBJECT LOCATION STATE OF THE ART

Lieutenant R.G. Williscroft
Atlantic Marine Center Diving Office

ABSTRACT

Underwater surveying falls into two distinct categories, direct and indirect. Indirect surveying is subdivided into non-acoustic and acoustic methods. Non-acoustic surveying consists of optical and electrical techniques. Acoustic surveying is accomplished with an acoustic grid or by phase measurement techniques. The state of the art in each area is discussed, with special attention being paid to the electronic based indirect methods most prevalent today. The special requirements for diver safety generated by unique underwater environments such as high current, low visibility, very cold water, and polluted water are looked at in detail. Special situations requiring the use of sophisticated diving methods such as saturation diving and mixed gas diving are reviewed. The use of divers for underwater survey and object location is compared to other modern methods with particular attention being paid to the suitability of divers and to their cost effectiveness.

INTRODUCTION

There are basically three approaches to underwater survey which are broken down into two broad categories loosely defined as direct and indirect survey methods.

Woods and Lythgoe (1971) in their reference work Underwater Science give an excellent description and review of direct methods that have been used under various diving conditions for relatively large scale surveys. The NOAA Diving Manual (U.S. Dept. of Commerce, 1979) discusses direct methods for high accuracy, localized surveys, such as might be used in the vicinity of a wreck or other high-interest domain. It also explores some of the direct measures employed during large scale surveys.

Most underwater direct survey methods are outgrowths of land-based procedures modified for the underwater environment. They utilize optical devices such as theodolites, tapes, lines, grids, and various other pieces of land surveying equipment that have been developed over the years. On the larger scale, direct methods employ means of augmenting the diver's ability to cover large amounts of territory.

Indirect underwater surveying currently is either photographic or acoustic, although recent work in electric current fields has also produced

encouraging results (Williscroft & MacLeod, 1978). Photographic techniques are limited in their applicability to special situations and are discussed in detail by Mertens (1970), Woods and Lythgoe (1971), and McNiel (1972). NOAA Commander Floyd Childress has written a lively account of a recent photogrammetric survey of the USS MONITOR wreck for NOAA MAGAZINE (Childress, 1977) which graphically details some of the inherent problems in underwater photogrammetry.

There are two acoustic survey methods. The "acoustic grid" is the acoustic equivalent of direct trilateration as applied to land surveying. "Phase measurement" is the acoustic equivalent of Electronic Distance and Angle Measurement (EDAM) as applied to land surveying.

DIRECT METHODS

There are a wealth of available equipments and techniques for direct underwater survey and object location. These range from using a standard surveyor's theodolite (where the water is clear enough to do this and the user has sufficient patience to undertake the daily cleaning necessary to prevent corrosion) to specially designed glass fiber tapes for accurate small scale measurement. With the exception of long distance triangulation, many of the methods used in land surveying can be used underwater. Over the years specialized techniques and equipment have been devised specifically for such work. These are fully described by Woods and Lythgoe (1971).

ACOUSTIC GRID

In its simplest form, the acoustic grid consists of three transponders placed at known positions on the sea bottom. They are sequentially interrogated from within their established grid, and the time delay for each response is measured and recorded. If the velocity of sound in sea water for that area and time is known, the time delays for the three responses represent the three distances by a known mathematical reationship.

The least expensive "acoustic grid meters" are just this simple. Transponders are implanted and their positions are determined using a direct underwater survey method. The interrogator is a small, hand-held directional sonar device which has a digital read out of the time delay. The diver places himself above the point to be surveyed, aims visually at the first transponder and takes a number of readings (which are later averaged). This process is repeated for the other two transponders. The sound velocity parameters, salinity, temperature and pressure, are measured. Circumstances will dictate whether the position is resolved in-situ, or later ashore.

A first order improvement to this system is to increase the number of transponders to four or even five. The redundancy thus supplied results in a significant improvement to final position determination.

More sophisticated versions of the acoustic grid survey system are available, most of which read out range directly. Although more convenient to use, these systems suffer either from inaccuracies introduced by their using a fixed sound velocity (usually 1,500 m/sec), or the inconvenience of a variable input, which requires on-site determination of sound velocity instead of simple parameter measurement.

An excellent in-depth treatment of the acoustic grid is given by Kelland (1976) in his description of North Sea planimetric survey work. He demonstrates the value of this method, particularily when a site must be visited over and over again to measure a varying feature, such as the motion of sand waves. Since all measurements are taken relative to the acoustic grid, a survey by this method will be internally complete. A geodetic reference, if required, can be established at any time.

The acoustic grid has two major drawbacks. The first is the requirement to accurately know the relative positions of the transponders, which necessitates some sort of direct survey prior to resolving positions within the grid. The second disadvantage is the system's planimetric character, its inability to resolve vertical information, which makes it inconvenient for many underwater applications where vertical information is important.

PHASE MEASUREMENT

Unlike the acoustic grid which determines the position of an object relative to a fixed network of transponders, phase measurement is self-contained within the support vessel, except for one mobile transponder.

In principle, three receiving elements are precisely located with respect to each other on the underside of the support craft. An interrogator is also placed on the craft's underside. A transponder is diver emplaced on the object to be surveyed (or, wearing the transponder, the diver places himself on the object), and is interrogated by the ship. The return signal as received by the three receiving elements is phase analyzed to resolve azimuth, dip and range. As in acoustic grid surveys accurate sound velocity determination is required for precision results, and unlike the grid, it must be an in-situ determination, not just parameter measurement. With continuous communication and periodic interrogation (i.e. at two second intervals), the directed position of a diver can continuously be monitored. It is thus possible to establish the three-dimentional boundaries of an underwater object by simply having the diver swim the edges.

The disadvantage of having to make in-situ sound velocity determinations is more than offset by the gain of vertical information, and by there being no requirement for a preliminary direct survey.

SOUND VELOCITY IN SEA WATER

In both acoustic grid and phase measurement survey systems accurate determination of speed of sound in sea water is necessary. Kelland (1976),

during his North Sea planimetric work, measured salinity, temperature and pressure and applied them to the Wood (1949) equation for the speed of sound in sea water as part of hs post measurement analysis process. His reported data reduction inaccuracies and his position uncertainties can be significantly lowered by applying the same parameters to the more recent Wilson (1960) equation for speed of sound in sea water.

Complete tabulations of the Wilson equation are available from the U.S. Naval Hydrographic Office (1962), and their use is strongly recommended when field determination of sea water sound velocity is necessary. The entering arguments are salinity, temperature and pressure, and any error in measuring these parameters will affect the outcome. Applying Kelland's processing to the Wilson equation (Williscroft, 1978), it can be shown that for constant depth, the error in meters in a distance valve dx simplifies
to:

$$dx = Vdt = (4.9656 - 1.1244\times10^{-2}S - 8.9118\times10^{-2}T - 7.8135\times10^{-4}T^2 + 3.1940\times10^{-5}T^3 - 1.8718\times10^{-2}P)tdT + (1.2796 + 3.3840\times10^{-3}S - 1.1244\times10^{-2}T)tdS$$

where V = sound velocity in m/sec
T = temperature in deg C.
S = salinity in 0/00
P = depth as pressure in kg/cm^2

The effect of this equation on position accuracy obtained with any acoustic survey method is to make the analysis problem salinity critical in normal temperature ranges, with an increasing requirement for accurate salinity and temperature measurements in shallow, cold water. Very shallow water measurements are significantly affected by temperature errors. Accurate results depend upon keeping salinity and temperature measurement errors small enough so that the velocity errors they introduce are less than the inherent equipment introduced errors.

DIVER SAFETY

Any operation involving human beings mandates a high priority for their safety. Diving, while perhaps no more dangerous than crossing a busy city street, is nevertheless a hazardous activity. The NOAA Diving Manual (U.S. Dept. of Commerce, 1979) clearly defines those dangers inherent to diving, and since they are part of the overall diving picture and not uniquely related to underwater survey and object location they will not be further treated here. However, there are situations actually generated by these activities and there are environments associated with these activities which pose special threats to the diver.

When a wire drag ship makes a hang in New York Harbor in January, the diver investigating it is faced with zero visibility, high current, very

cold water which is highly polluted. And there is every liklihood that the hang is covered with monofiliment line. Each of these situations poses a threat and requires special training, and in the case of cold and polluted water, requires special equipment as well.

A new diver graduating from the current NOAA Basic SCUBA Diving Course will be experienced in zero visibility, high current, and cold water diving. He will have learned to avoid entrapment where possible and how to cut himself free when necessary. The graduate from the NOAA Divemaster Course will have gained experience in supervising these situations including actual extractions of entrapped divers. He will also have mastered the requirements for managing an injured diver and will have gained experience in actual treatments. NOAA offers additional training in polluted water diving techniques and in surface supply and mixed gas procedures.

SPECIAL SITUATIONS

Where the area of investigation is particularly deep, it is possible to lessen the decompression time normally required or to lengthen the amount of time available on the bottom by using the special breathing gas mixture NOAA NITROX I, a mixture of 32% oxygen and 68% nitrogen. Where situations warrant divers specially trained in the use of this gas and the associated equipment can be made available to the ship.

Detailed work in water deeper than 33 feet which promises to extend over a relatively long period of time can best be managed by a team of divers who work out of a habitat, living on the bottom for the duration of the project. These divers are said to be saturated, and by operating in this mode they avoid the long and tedious decompression which would otherwise be necessary following each dive. Instead, at the end of the project (or their projected stay underwater) they decompress once.

COMPARISONS

When should divers be used? The answer is really twofold. When there is no viable alternative, divers must be used. And, when time constraints, or cost constraints, or any other constraint makes using divers more desirable than other methods.

Only divers can identify and parametize an underwater obstruction in low visibility water. Indeed, any time high discrimination is required, either visual or tactile, divers are necessary. A complete search of an area having relatively good visibility can be accomplished using a bottom wire drag, but by towing two divers over the bottom using a sled or other device with which they can control their depth the same area can be searched as quickly using only one vessel with the added benefit of visual identification of all items of interest.

Phase measurement offers an attractive means of quickly identifying both position, coverage and least depth for any object within the diver's depth capability. The suitably equipped launch upon locating an underwater obstruction could put divers in the water, continuously keeping track of their position and depth as part of the real time position plot. When interfaced with current hydrographic equipment and properly coordinated with current doctrine, the time savings alone would appear to justify development cost for this equipment.

The cost of maintaining a commissioned diver on board a NOAA ship averages about $1,500 per year, which includes all expenses including dive pay. More complete utilization of a four diver compliment would not significantly increase this annual cost. Additional equipment as discussed in this paper would not have to be physically integrated into the shipboard or launch system. Phase measurement systems are available mounted on a mast which can be extended over the side of a launch. With suitable hardware interface and software support such a system could be maintained at the Marine Centers for field use as required. Acoustic grid systems are inherently portable, requiring no on-board hardware at all. However, it should be remembered that some sort of direct survey is necessary prior to resolving points within the grid; and the grid itself must also be geodetically positioned.

SUMMARY

Underwater survey methodology has long been the child of dated land survey techniques. The introduction of the acoustic grid during the last decade and subsequent application to diving situations was a significant step forward. With the development of operational phase measurement diver tracking systems, underwater acoustic surveying has come of age. Coupled to a land-based hyperbolic positioning system, a properly outfitted craft can now accurately position and define an underwater object in depth and geodetically, and can conduct rapid, accurate underwater surveys.

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IMPROVING LAUNCH ECHO SOUNDING GRAPHS

by

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1980

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A.D. O'Connor

Abstract

This report deals with the problems Pacific Region faces in acquiring satisfactory echo soundings. Poor, noisy echo soundings that can be interpreted by hydrographers, defy digitization, an important step along the automated way.

Transducer installation and an alternate propulsion system are investigated in an attempt to increase the signal to noise ratio of echo soundings.

Introduction

Prior to 1968 most of the echo sounding in Pacific Region was carried out using Kelvin and Hughes MS26B (14 KHz) echo sounders. These sounders were installed in 25 ft wooden displacement hull launches, powered by 4 cylinder diesel engines, which were capable of about 8 knots.

In 1968, Pacific Region acquired its first Bertram launch. This launch, PETREL, was capable of about 16 knots. An MS26B was fitted in PETREL and satisfactory results were obtained in depths to about 200 metres. As the launch moved into deeper water noise began appearing on the sounding graph to the point when a speed reduction was required to maintain an acceptable graph. A second Bertram, BARRACUDA, was acquired in 1969. This launch was equipped with an Edo 9040 (24 KHz) echo sounder. As with PETREL, BARRACUDA could sound at speed to 200 metres but had to slow down for deeper soundings.

More Bertrams have been added to the fleet. They have been fitted with various sounders but results to date have been similar to those realized in PETREL and BARRACUDA. Figure 1 is an example of a sounding graph from the Ross 400A Fineline echo sounder (100 KHz) on board the

Bertram launch, BRIGHT, during the 1979 Laredo Sound survey. Graphs such as this are routinely being "interpreted" by hydrographers assigned to our Bertram launches.

The six Bertram launches in Pacific Region are powered by Detroit Diesel 6V-53N engines. Acoustic noise is generated by the engine, power train, and by cavitation around the propeller.

While the level of noise varies from launch to launch, in all cases it is sufficient to seriously impair the quality of echo sounding graphs obtained, at speed, in depths of 200 metres or more.

With the advantage of hindsight, it is easy to see that our move to faster noisier launches has coincided with our move to higher frequency sounders. These sounders have a shorter range, due to attenuation, than lower frequency sounders given a similar power output.

The hydrographer faced with a weak signal from the seabed in deeper water, amplifies the signal by manipulating the gain control. The manipulation also amplifies the acoustic noise, present regardless of depth, and the resulting sounding graph resembles that in Figure 1.

Again with hindsight, our move to faster noisier launches equipped with higher frequency sounders has paralleled our move into the automated logging of survey data. Digitization of echo soundings is a vital requirement in automated surveys, it is also the phase of our operations that has enjoyed the least success. A digitizer needs a strong sharp noise-free signal or pulse in order to function. Digitizers tested to date have not had this ideal digitizable signal and have not performed well. If the acoustic noise discussed earlier could be suppressed and relatively noise-free soundings obtained then serious

200 METRES
BOTTOM
ACOUSTICAL NOISE PRESENT
LAUNCH CSL BRIGHT
SPEED 14 KNOTS
LOCATION LAREDO SOUND
DATE 18 JULY 1979
SOUNDER ROSS 400A
FREQUENCY 100 KHZ
GAIN 8
PAPER SPEED 3
POWER OUTPUT 500 WATTS
300 METRES
FINE LINES
SENSITIVITY
FULL SPEED

Figure 1

consideration could be given to acquiring a satisfactory digitizer. Some success has been experienced with digitizing ship soundings but power, transducer size, transducer location, and frequency restrictions on board ship are not as stringent as those on launches.

Trials

In 1979 a study was undertaken to optimize the sounding graphs that could be obtained from the echo sounders and launches presently in use. By reducing or eliminating acoustic and/or electrical noise from the launch machinery and propeller a better, more readable, and digitizable sounding graph should be obtained. Two transducers (50 KHz and 100 KHz) were installed in various locations in PETREL. Sounding graphs obtained at each location indicated that, as could be expected, the level of noise decreased as distance from the machinery increased. However if the transducer was moved too far forward noise from the bow wave was encountered. A compromise was reached and a large diameter transducers well was installed as shown in Figure 2. A section of PETREL's 1 inch hull was removed and a thin, 1/8", fibreglass window installed at the bottom of the well. The well extended above the water line in case of failure of the window. The top of the well was left open to permit the rapid installation and removal of the various echo sounder transducers to be tested. Fresh water in the well acted as an efficient medium between the transducer and the sea. Static electricity is generated by the engine and drive train. This energy is radiated from the propeller shaft and appears as noise on the sounding graph. To reduce this form of noise a carbon grounding brush was applied to the shaft. An alternator suppressor kit was installed on the alternator to

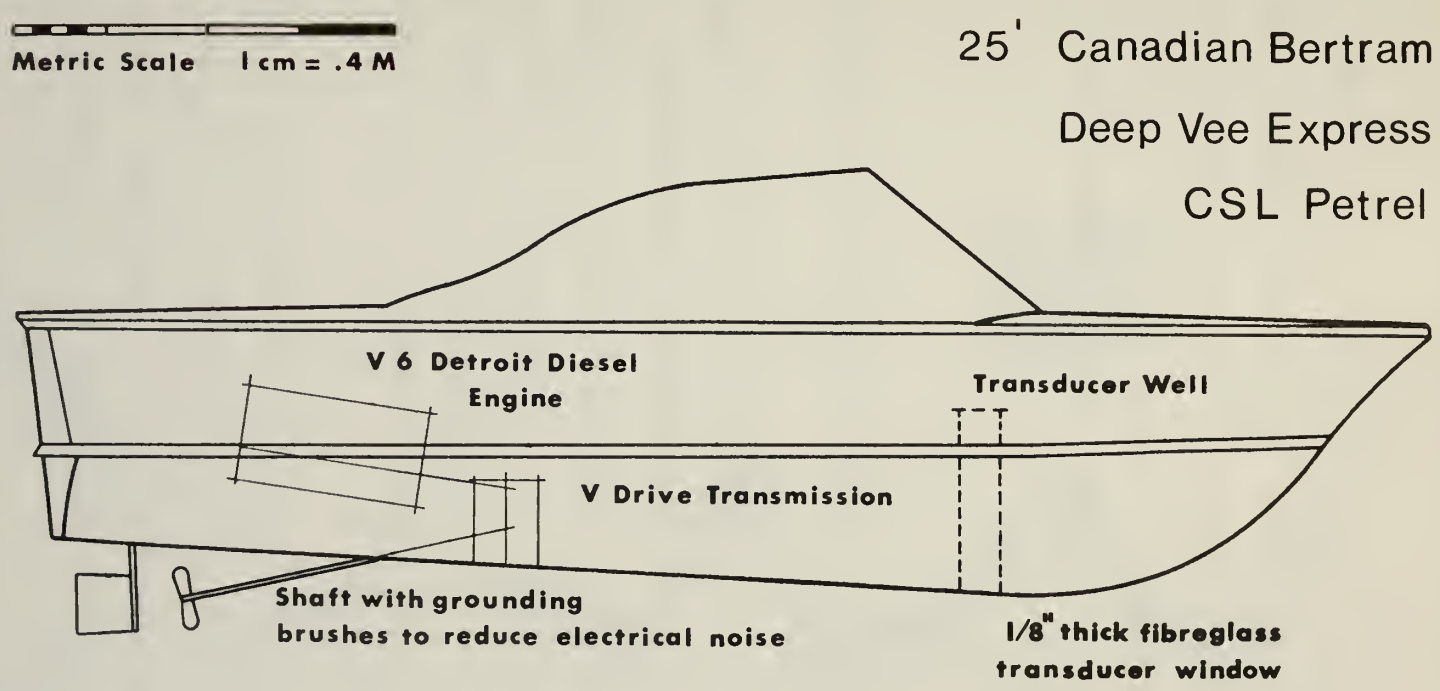

Metric Scale 1 cm = .4 M
25' Canadian Bertram
Deep Vee Express
CSL Petrel
V 6 Detroit Diesel
Engine
Transducer Well
V Drive Transmission
Shaft with grounding
brushes to reduce electrical noise
1/8" thick fibreglass
transducer window

Figure 2
21-5

eliminate another possible noise source. Finally the echo sounders were run from an isolated power supply (two 12 V. batteries).

Echo Sounders

Four sounders were used in the study, three of which are currently in use in Pacific Region and a fourth of which is under consideration. Ross 400A Fineline, 100 KHz, power output 500 watts; Ross 801 Portable, 50 KHz, power output 1000 watts; Atlas Deso 10, 30 and 100 KHz, power output 175 watts; Simrad Skipper 802, 50 KHz, power output 1000 watts.

Tests

A test range was established in Haro Strait, maximum depth on the range is about 380 metres.

The sounders in PETREL were run in turn over the test range at 16 knots and in all cases the graphs showed marked improvement (Figures 3-6). Some noise was still apparent, particularly on the sounders with higher frequency and/or lower output characteristics, but the records were all clearly superior to those obtained prior to the modification initiated under this study. The high powered low frequency sounders performed particularly well.

The mechanically and electrically generated noise levels were sufficiently reduced to allow readable and perhaps digitizable soundings to be obtained. The noise still present on the graphs indicated a potential problem in areas of deeper water or with poorer bottom sound reflecting qualities.

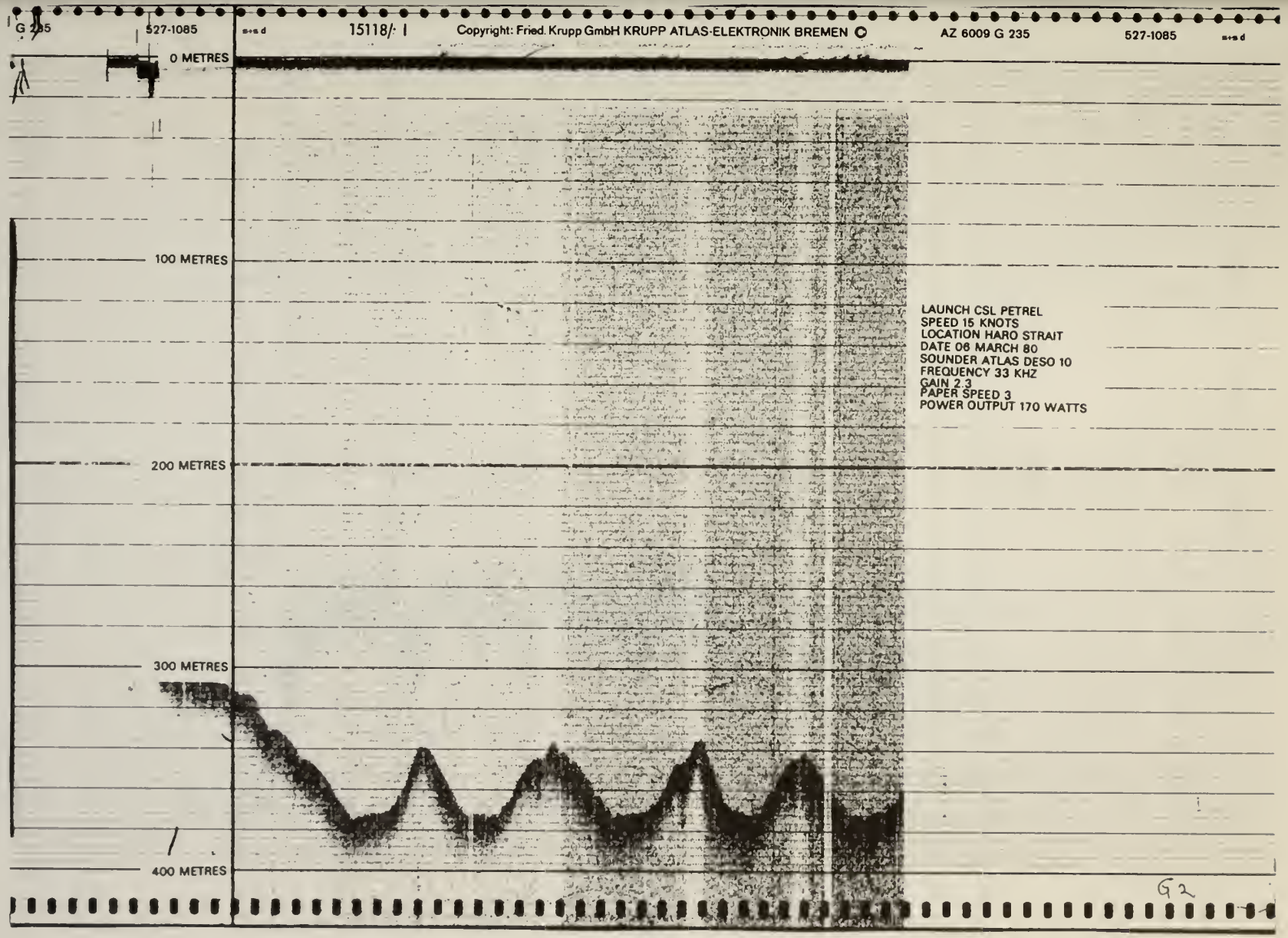
A major source of acoustic noise is cavitation around the

LAUNCH CSL PETREL
SPEED 15 KNOTS
LOCATION HARO STRAIT
DATE 06 MARCH 80
SOUNDER ROSS 400A
FREQUENCY 100 KHZ
GAIN 8
PAPER SPEED 2
POWER OUTPUT 500 WATTS
FINELINE OFF
300 METRES
350 METRES
400 METRES

Figure 3

LAUNCH CSL PETREL
SPEED 15 KNOTS
LOCATION HARO STRAIT
DATE 06 MARCH 80
SOUNDER ROSS 801
FREQUENCY 50 KHZ
GAIN 3
PAPER SPEED 2
POWER OUTPUT 1000 WATTS
ELECTRICAL NOISE ORIGINATING IN SOUNDER
300 METRES
350 METRES
400 METRES

Figure 4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Copyright: Fried. Krupp GmbH KRUPP ATLAS-ELEKTRONIK BREMEN ©
AZ 6009 G 235
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s+s d
0 METRES
100 METRES
200 METRES
300 METRES
400 METRES
LAUNCH CSL PETREL
SPEED 15 KNOTS
LOCATION HARO STRAIT
DATE 06 MARCH 80
SOUNDER ATLAS DESO 10
FREQUENCY 33 KHZ
GAIN 2.3
PAPER SPEED 3
POWER OUTPUT 170 WATTS
G2

Figure 5

LAUNCH CSL PETREL
SPEED 15 KNOTS
LOCATION HARO STRAIT
DATE 06 MARCH 80
SOUNDER SKIPPER 802
FREQUENCY 50 KHZ
GAIN MINIMUM
PAPER SPEED MAXIMUM
POWER OUTPUT 1000 WATTS
300 METRES
350 METRES
400 METRES
450 METRES
500 METRES
550 METRES

Figure 6

blades of the propeller. PETREL is equipped with a 19"x19" propeller turning about 1800 RPM at full speed. Having moved the transducer as far from the propeller as possible noise still appeared on the record although at reduced intensity. If the launch could be powered by a propulsion system other than a propeller further reduction of noise levels might be anticipated. Water jet driven boats, the engine driving a water pump rather than a propeller, have been available for some time. If a water jet drive could be used, a source of noise (cavitation around the propeller) would be eliminated. Lack of funds prevented the purchase and installation of a jet drive in PETREL, however, funds were available to rent a water jet driven launch, the SEATECH JET, Figure 7.

SEATECH JET is an aluminum launch 31 feet in length. She is powered by a Caterpillar 3160 diesel engine developing 210 HP driving a 16" Berkley pump. With an all up weight of 9500 lbs SEATECH JET was capable of 24 knots. A transducer well, similar to that in PETREL was installed in SEATECH JET. The same sounders were run over the same range as in PETREL and under similar conditions. The resulting sounding graphs, Figures 8-11, showed further improvement in signal to noise ratio. All of the sounding graphs were virtually noise free and again the low frequency high power sounders produced superior graphs.

As a final test, both launches were run at full speed over a passive hydrophone installed at the I.O.S. wharf in Patricia Bay. The results of these runs are represented in Figure 12, acoustic noise generated by SEATECH JET at 24 knots was about 5 db lower than in PETREL at 16 knots. Figure 12, does not indicate absolute noise levels, but illustrates the significant difference in relative noise levels.

PETREL at 15 Knots

SEATECH JET at 24 Knots

Figure 7

300 METRES
350 METRES
400 METRES
LAUNCH SEATECH JET
SPEED 15&20 KNOTS
LOCATION HARO STRAIT
DATE 06 MARCH 80
SOUNDER ROSS 400A
FREQUENCY 100 KHZ
GAIN 8
PAPER SPEED 2
POWER OUTPUT 500 WATTS
FINELINE OFF
20 KNOTS
15 KNOTS

Figure 8

300 METRES
350 METRES
400 METRES
ELECTRICAL NOISE ORIGINATING IN SOUNDER
20 KNOTS
LAUNCH SEATECH JET
SPEED 15620 KNOTS
LOCATION HARO STRAIT
DATE 29 FEBRUARY 80
SOUNDER ROSS 801
FREQUENCY 50 KHZ
GAIN 3
PAPER SPEED 2
POWER OUTPUT 1000 WATTS

Figure 9

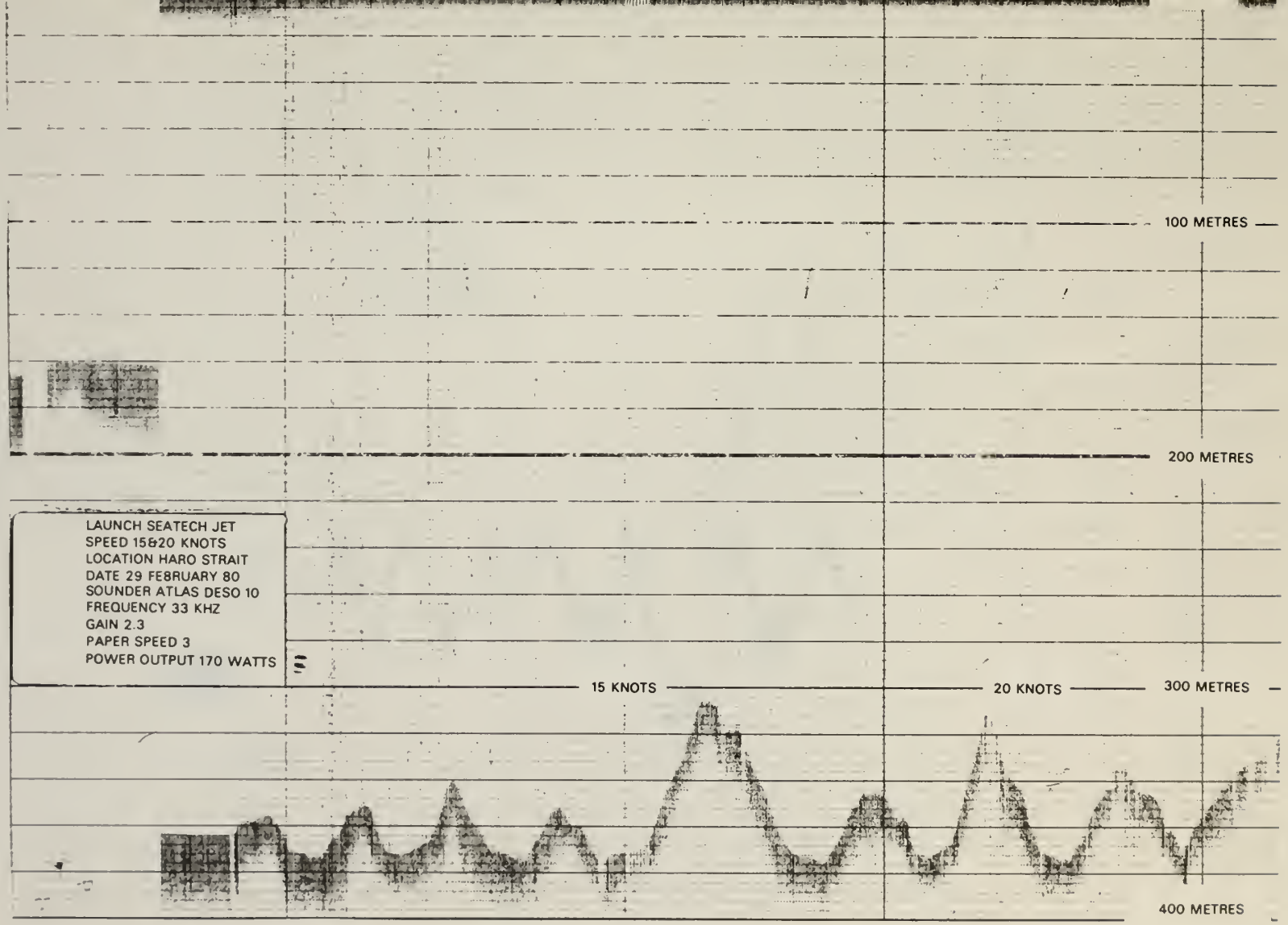
100 METRES
200 METRES
LAUNCH SEATECH JET
SPEED 15&20 KNOTS
LOCATION HARO STRAIT
DATE 29 FEBRUARY 80
SOUNDER ATLAS DESO 10
FREQUENCY 33 KHZ
GAIN 2.3
PAPER SPEED 3
POWER OUTPUT 170 WATTS
15 KNOTS
20 KNOTS
300 METRES
400 METRES

Figure 10

250 METRES
300 METRES
350 METRES
400 METRES
450 METRES
500 METRES
550 METRES
LAUNCH SEATECH JET
SPEED 15&20 KNOTS
LOCATION HARO STRAIT
DATE 29 FEBRUARY 80
SOUNDER SKIPPER 802
FREQUENCY 50 KHZ
GAIN MINIMUM
PAPER SPEED MAXIMUM
POWER OUTPUT 1000 WATTS

Figure 11

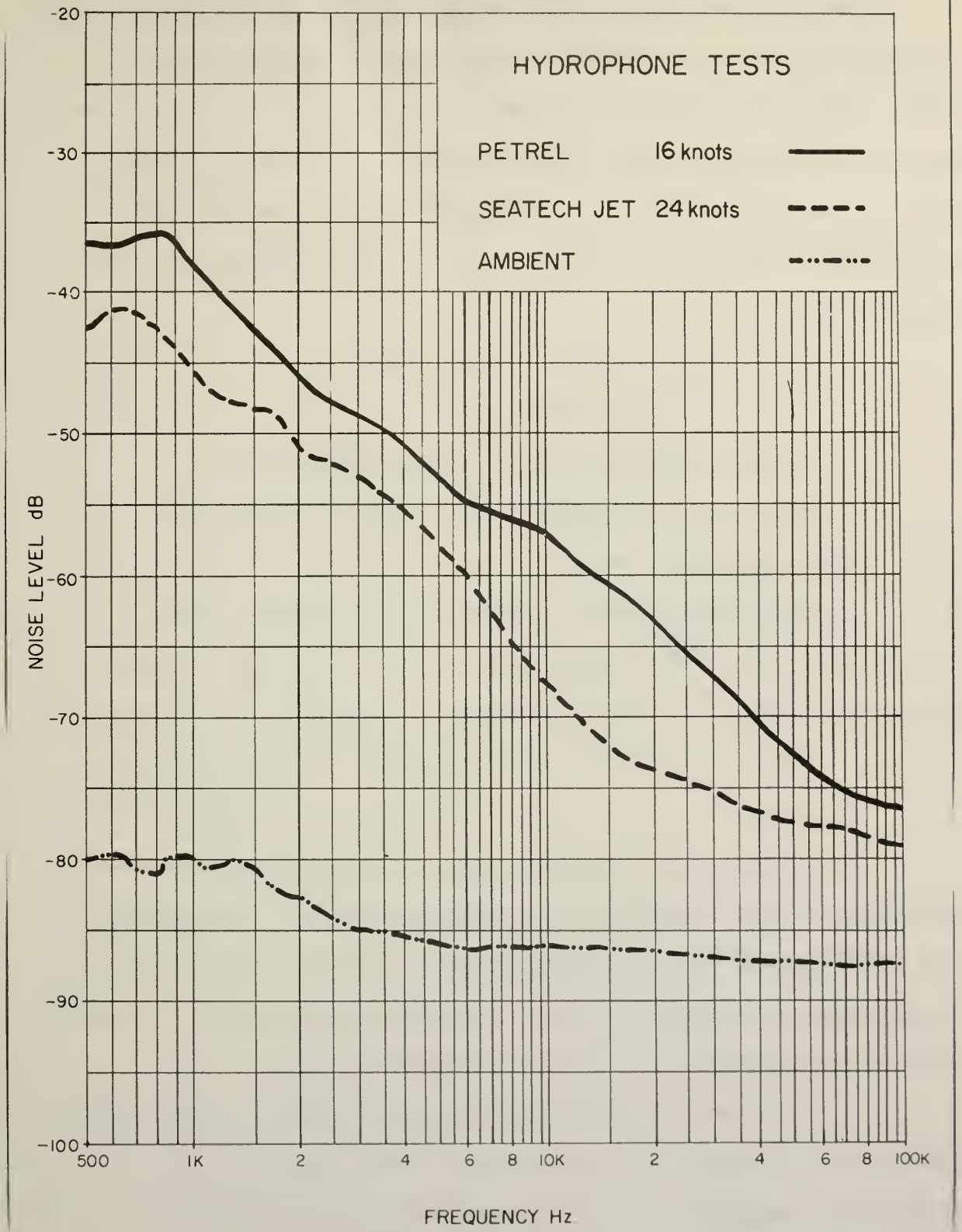
HYDROPHONE TESTS
PETREL 16 knots
SEATECH JET 24 knots
AMBIENT
-20
-30
-40
-50
-60
-70
-80
-90
-100
NOISE LEVEL dB
500
1K
2
4
6
8
10K
2
4
6
8
100K
FREQUENCY Hz

Figure 12

Conclusions

Noise is generated by the machinery on board our survey launches and by cavitation around the propeller. This noise appears on the sounding graph, particularly when sounding in deeper water, and interferes with or obliterates the signal from the sea bed. This study has shown that this launch-generated noise can be suppressed or eliminated with higher quality echo sounding graphs resulting. Improved sounding graphs can be obtained by:

1. Judicious placement of the transducer.
2. Grounding of the machinery.
3. Installation of electrical noise suppression kits.
4. Use of an isolated power supply for the echo sounder.

Further improvements can be made by:

5. Use of echo sounders operating at 50 KHz with a power output of 1000 watts.

Superior sounding graphs can be obtained by:

6. Replacement of the launch propeller by a water jet drive system.

In the early stages of this study it became apparent that Pacific Region does not have an adequate echo sounder digitizer. Consequently these trials have been directed at improving the quality of our echo sounding graphs on the premise that digitization is relatively straightforward given a large signal to noise ratio.

One point that should be made is that all echo sounding graphs appearing in this report were obtained under ideal weather conditions and may not be repeatable under all actual field survey conditions

(ie. rough seas), however, they do portray the significant improvements that can be made over our existing capabilities (ie. Figure 1 vs Figure 10).

Recommendations

1. Under present constraints

I recommend that:

a. A transducer well, large enough to accommodate all transducers presently in use, be installed in all launches in a position similar to that in PETREL. See Figure 13, for details of well.

b. The launch machinery should be grounded.

c. Alternator noise suppression kits should be fitted.

d. An isolated power supply be used for the echo sounder.

e. For sounding in deeper water a low frequency/high power echo sounder should be used (the recommended well will enable transducers and therefore echo sounders to be changed readily).

2. Future equipment

In addition to the above I recommend that:

a. New sounders purchased for regular surveys operate at a frequency of 50 KHz with a power output of 1000 watts. Higher frequency sounders will no doubt be required for special projects but their wholesale purchase is not recommended. All sounders under consideration should be run, in PETREL, over the test range so that an unbiased comparison of relative performance can be made.

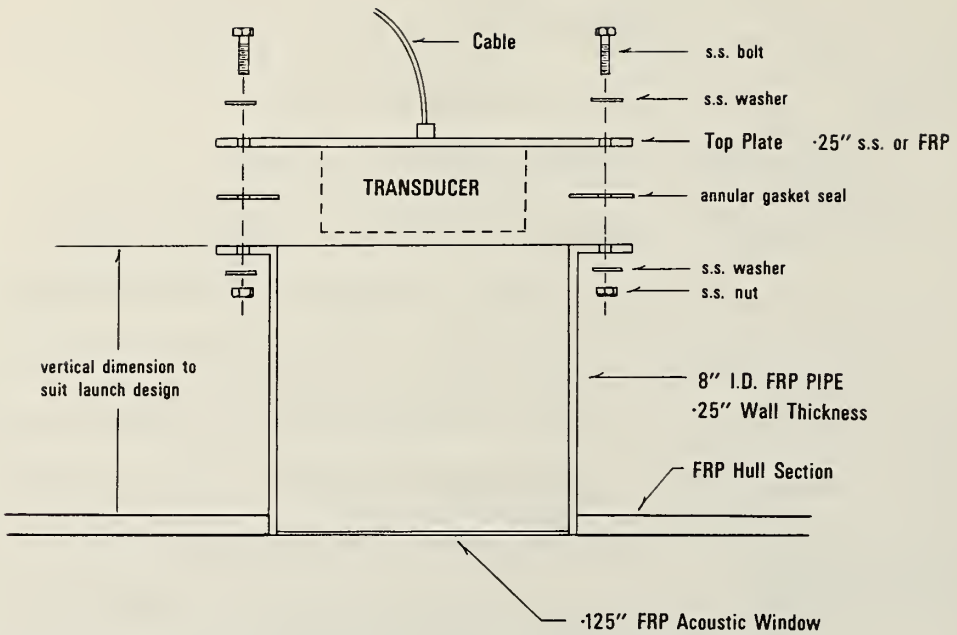
Cable
s.s. bolt
s.s. washer
Top Plate ·25" s.s. or FRP
TRANSDUCER
annular gasket seal
s.s. washer
s.s. nut
vertical dimension to
suit launch design
8" I.D. FRP PIPE
·25" Wall Thickness
FRP Hull Section
·125" FRP Acoustic Window
TRANSDUCER WELL

Figure 13

b. New launches should be powered by diesel engines and water jet drive systems.

In addition to substantially reducing acoustic noise levels, the water jet eliminates the risk of damage to the propeller/shaft/rudder, also the V-drive and reduction gear are removed from the drive train. Weight may be a problem, the 31 ft aluminum SEATECH JET, fully loaded weighed 9500 lbs; her 210 HP engine and 16" pump produced 24 knots. The 25 ft fibreglass PETREL similarly loaded, weighed 10,500 lbs; her 197 HP engine and conventional drive produced 16 knots. If 25 ft fibreglass launches must weigh in the region of 9800 lbs without equipment or personnel on board, a close look must be taken at aluminum launches.

Anticipating intuitive doubts about the steering or sea-keeping qualities of water jet driven launches I direct the reader's attention to reference 2.

c. Development must begin now, of an echo sounder digitizer that can accommodate all survey launch echo sounders.

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MR. O'CONNOR: I would be pleased to answer questions.

CDR MEL GRUNTHAL, NOAA: Tony, was there any consideration given to more advanced propeller design, anticavitation-type propellers?

MR. O'CONNOR: No, we looked into existing literature on cavitation and propeller design, but it was a case of trying to make the equipment we have work, rather than start designing a launch.

LCDR ALAN J. PICKRELL, NOAA Ship FAIRWEATHER: You recommended 50 kilohertz frequency for the sound pulse. How does that change the beam width of your echo sounder, for instance, the Ross, going from the 100 kilohertz to 50?

MR. O'CONNOR: The beam width, of course, varies with sounders. The 50 kilohertz sounder we were using is a 30 degree beam width. The higher frequency one, I think, was 22 degrees. The Ross 100 kilohertz sounder was 22 degrees. 50 was 30 degrees.

CDR FISHER: I think I found out what it means to be moderator and why I'm moderator, and that is I have no forum for asking a question, which is of benefit to you all. I would, however, encourage some conversation with Tony, I think outside of this meeting here, on the aspect of the way they are looking at the data enhancement. I'm not sure we have done that. I don't know of any reports or any I have had access to. And also the system of locating the transducer is somewhat different than I'm familiar with, plus I think we can offer from our side some past experience with water jet boats.

We have one of our past branch chiefs here and the present branch chief, too, I believe, that have been using that type of boat for a while. And Tony indicates he talks very well off the job, so I don't know, does that indicate we should immediately put one there?

SOUND VELOCITY DISPLAY SYSTEM COMPLEMENTS

SIDE-SCAN SONAR

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ABSTRACT

A system which provides real-time sound velocity profiles and near real-time ray diagrams was utilized during the 1980 Beaufort Sea Survey to complement side-scan sonar operations. The system, developed at the Institute of Ocean Sciences, combines off the shelf hardware with simple software to create a versatile shipboard system.

The system is described and field results are examined. The "on-line" application of the displayed information, a technique which provided a more thorough understanding of the side-scan sonar records, is discussed.

ACKNOWLEDGEMENTS

Thanks for your input and assistance:

- Tony O'Connor, Hydrographer-in-charge, 1980 PANDORA II Western Arctic Survey, who provided input from the concept stage through to field testing and who put up with me and my tests during his production survey.
- Bob Burchsted, Engineer and Side-Scan Operator par excellance with Klein Associates Inc., who operated the leased side-scan system during the trials.
- Surveyors, Ships Officers and Crew who took part in the 1980 Western Arctic Survey aboard the PANDORA II.
- HARP (High ARctic Research Program: a Canadian Ministry of Transport administered program) for the funding.

INTRODUCTION

By late 1979 the Canadian Hydrographic Service (CHS), Pacific Region, based at the Institute of Ocean Sciences near Sidney, British Columbia, had identified a need for and had set in motion a development project to provide a deck unit with which to acquire sound velocity measurements. The existing equipment, a printer/frequency counter lash-up, had exhibited serious shortcomings particularly when used with expendible sound velocimeters (XSV's).

A second requirement, also related to sound velocity, was established during the initial stages of this XSV deck unit development project. Renewed interest in side-scan sonar as a tool for detecting the Pingo-Like-Features (massive frost heaves) which occur in the Beaufort Sea pointed to the requirement for a technique and equipment which would enable the determination of both an optimum tow depth for the side-scan sonar fish and an estimate of the resulting bottom coverage. The side-scan operations were to take place in water depths which varied from 20 metres to 200 metres in areas of the Beaufort Sea which at times have a surface layer up to 10 metres in thickness of relatively warm, fresh water. Clearly, under these conditions the refraction or ray-bending problems associated with the achievement of 1200 metre swath widths using side-scan sonar techniques are significant. The XSV Deck-Unit development project, expanded to accommodate these additional requirements, was underway.

Figure 1. Expendible Sound Velocity Probe (XSV) and Hand Launcher

SYSTEM DESIGN CONCEPT

The general conceptual design for the system was based upon those well used pseudo-specifications:

- low cost
- minimum development time and effort
- flexible and easily expandible
- easy to use
- must meet shipboard, hydrographic requirements
- high reliability

The specific requirements were examined and it was determined that they as well as the general specifications could best be accommodated by a software driven system which was based to as great an extent as possible on off-the-shelf hardware. The system was to provide near real-time CRT displays of both velocity profile and ray-trace plots, hard copy of both data records and plots in addition to magnetic tape storage of velocity data.

SYSTEM DESIGN - HARDWARE

The hardware development effort was, by virtue of the early decision to utilize off-the-shelf equipment, reduced to an instrument selection task. A number of microcomputer systems were under consideration when Hewlett Packard introduced the HP-85. In this system HP had incorporated in a single, typewriter-sized package the complete complement of peripherals required for the sound velocity deck unit. This microcomputer was selected for the task primarily on the basis of this single package concept but also because of these additional features which simplified the overall development and eliminated completely the need to develop hardware:

- integral, real-time clock

Figure 2. Sound Velocity Deck Unit Hardware (HP85 & HP5300)

- programmable timers for real-time interrupts
- CRT with Graphics capabilities
- IEEE-488 interface capability (optional)

Other factors which influenced the decision to apply the HP-85 to this requirement included the apparent high quality of construction and what was presumed would be the high reliability of an HP product.

With the availability of the IEEE-488 interface bus the sensor interface task could be handled by an off the shelf IEEE-488 compatible frequency counter.

The hardware problems were reduced to a straightforward order-the-equipment procedure.

SYSTEM DESIGN - SOFTWARE AND ALGORITHMS

The software, written entirely in BASIC, has been organized as a number of tasks written as two separate systems: an XSV data acquisition and display package (XSVSYS) and a sonar ray-trace plotting package (RAYS). Although designed to require operator interaction for parameter inputs such as scale selection, sample rate, sonar fish depth, etc., these interactions are handled through a series of prompts, default values, input error detection and on-line instructions.

XSVSYS has been organized as an initialization task and an XSV splashdown detection task followed by background/foreground, real-time acquisition and delayed, or near real-time, computation and display tasks. Immediately following detection of splashdown, XSV period data is requested of the frequency counter by real-time interrupts issued by a preprogrammed, internal timer. During the slack time between samples (max. sample rate is 200 m sec.) the background tasks compute both sound velocity and depth for

each sample point and plot a near real-time sound velocity profile on the CRT display.

The calculations for depth and sound velocity are computed by substituting elapsed time from splashdown (t) into the XSV descent characteristic formula:

$$D = 5.3672\ t - 0.001476\ t^2$$

where: t is in seconds
D is in metres

and the measured period (T) into the XSV sensor characteristic equation

$$C = \frac{0.052}{\frac{T}{128} - 2\times10^{-7}}$$

where: T is in sec.
C is in metres/sec.

in accordance with Sippican supplied documentation.

Upon completion of the data acquisition task the timers are switched off and the background task takes over to complete the calculations and resultant velocity profile plot. The hydrographer is then supplied with a calculated average sound velocity for the sampled water column. This calculation utilizes a depth weighted averaging function to accommodate a variable sample rate.

$$\overline{C} = \frac{1}{2(D_N - D_1)} \sum_{i=1}^{N-1} (C_{i+1} + C_i)\ (D_{i+1} - D_i)$$

where: N = number of samples
D_i = Depth (in metres) of the i^{th} sample
C_i = Sound velocity (in metres/sec) at depth D_i

XSVSYS now formats and writes to magnetic tape the data file obtained from the XSV cast.

Program RAYS, using the magnetic tape resident data files, computes and develops, in a dynamic display, ray trace plots for the sampled water column. The plots are based upon operator supplied values for transducer depth, desired beam pattern limits and ray spacing interval. The refraction angle of the ray (θ), as it passes through the layers of the sampled velocity profile (C), is computed by direct application of Snell's Law.

$$\frac{\text{COS } \theta_1}{C_1} = \frac{\text{COS } \theta_2}{C_2} = \text{constant}$$

The rays are then traced out as a piecewise, linear plot and are made available to the operator in hardcopy.

SYSTEM OPERATION

The system has been designed to permit straightforward operation with the user routed through the procedure under the guidance of numerous prompts. Although it requires considerable operator interaction for manual entry of control and format parameters the system remains quite forgiving by providing numerous opportunities for the user to double-check and, if necessary, to modify, manual input in addition to providing automatic recovery from gross manual input errors.

The XSV data acquisition and processing portion of the system is automatically started upon power up provided the system tape has been preloaded in the drive. The first task of the operator is to initialize the system. This involves the manual entry of parameters such as administrative data (i.e. ship name, position, time, date, etc.), desired depth scale for the profile plot and the desired sample rates (vertical resolution on profile plot to max. 1 metre). The system, once initialized,

enters a "Waiting for Splashdown" mode where it flashes this notice on the CRT while sampling the XSV data port at high speed to detect probe splashdown. The operator, now free to attend to the launching of the probe, should not be required to intervene until the cast is complete. Upon detection of splashdown the system collects real-time data in a foreground task and computes and plots on the CRT, in near real-time, the velocity profile. Bottom detection, breakage of the XSV wire, exceeding the selected maximum depth, or operator intervention signal the end of the cast at which time the system produces a hardcopy of the header, the profile and the average velocity information. The operator can then request an optional hardcopy data list following which a prompt is issued to ensure that a data tape has been loaded. Once the file has been stored on tape the data can be accessed either for a rerun of the velocity profile software or for the ray-trace routines.

The ray-trace software operating procedure also begins with an initialization task. The input parameters in this case are the XSV cast data (profile as well as admin. header information) from a tape cartridge, sonar fish tow depth, sonar range, maximum upward directed ray angle, maximum downward directed ray angle and the desired ray angle interval. With the completion of the initialization the system proceeds to trace the rays on the CRT in a dynamic fashion (made slightly more interesting through the use of the HP-85 sound effects), ray by ray, developing in time the full ray trace diagram. Upon completion, the diagram is plotted on the thermal printer providing a hardcopy record and the operator has the option of rerunning the same data set using different tow depth or maximum range parameters.

RESULTS

Immediately following a series of successful tests casts in the IOS local waters of Saanich Inlet the system was taken in late July, 1980 into the Beaufort Sea aboard the PANDORA II for field trials. Approximately 30 XSV casts were made during the trials with an overall success ratio of about 70%.

Failures were generally attributable to one or more of three different causes:

- Type 1 Failure: Launch failure: probe strikes ship; probe hits ice; probe wire tangles with hydrophone array, etc. causing wire breakage.
- Type 2 Failure: System Failure: a read error or time out error causing an irrecoverable software failure; system fails to react as expected to certain input conditions; operator errors; etc.
- Type 3 Failure: XSV Start-up Failure: probe fails to commence operation immediately upon splashdown.

Both Type 1 and Type 2 failures were expected.

Type 1 errors were infrequent and within the bounds of what is generally considered normal operations. The failures described as Type 2 are of course the very reason for field trials that have long been an integral part of the development process. The system bugs were erradicated during the initial stages of the trials and although a few winter works "tics" remain a very useful system is now operational. The Type 3 failures were not expected and were characterized by a delayed start-up of the XSV probe. The delay between the instant of probe splashdown and the arrival of the data signal varied from about 200 msec (approx. equivalent to 1 metre of depth) on a successful cast to 3,000 msec (15 metres) and, in one case,

3,800 msec (20 metres) on an unsuccessful cast. Although still not fully explained it is believed that these problems may be related to the shelf life of the probes. Attempts to overcome this problem by using a launch tube to ensure a clean entry into the water and by presoaking the probe seemed to alleviate it to a great extent.

The sample (Figure 3) of the hardcopy output obtained during a cast provides an overall view of the data content and format available from the system. The velocity profile is a direct copy of the profile which is developed in near real-time on the system CRT. The depth weighted average velocity is available immediately upon completion of the cast as is the hardcopy printout and a magnetic tape record of the cast.

The velocity profile can be utilized immediately to determine the depth of the thermocline and thereby to ensure that the side-scan sonar fish is positioned below this zone of severe refraction. The data from the cast is also available for input into the ray-trace routines.

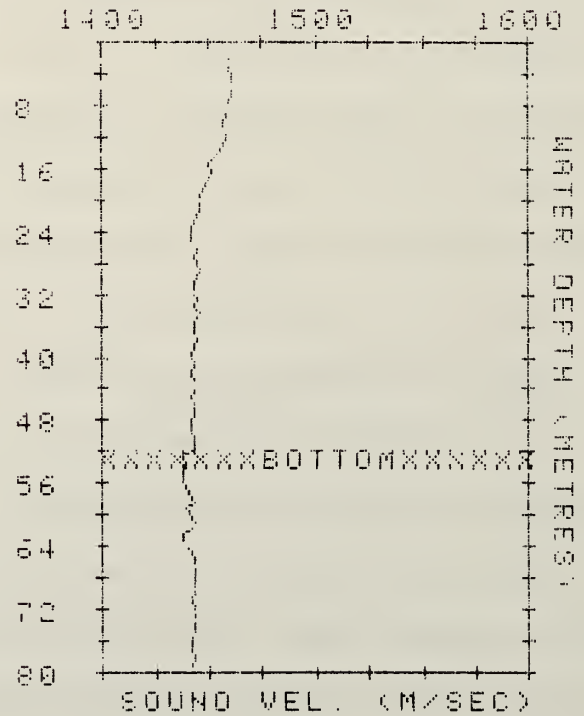
The ray-trace diagram shown in Figure 4 is computed from the velocity profile data obtained during cast WA-022. The diagram provides an indication of the probable refraction paths, along rays spaced every 2^{o}, of the acoustic energy contained in a side-scan sonar beam pattern which extends from 10^{o} above the horizontal to -20^{o} below. The calculations are based, in this example, upon a fish depth of 24 metres. The ray diagram provides confirmation of the extent of side-scan coverage. An iterative procedure based upon rerunning the ray-trace software using different tow depths can be used to optimize the tow-fish location in the water column.

XSV CAST

PANDORA 2 BEAUFORT SEA
DATE- 224/1980
TIME- 0400 GMT

STATION I.D.- WA-022
LATITUDE - RED 69.09
LONGITUDE- GRN 135.66

MAX. DEPTH ON SCALE = 80



OFF SCALE @ 80 METRES

FROM 1.7 METRES
TO 52.5 METRES
AVERAGE SPEED OF SOUND IN THE WATER COLUMN= 1447.74 M/SEC

DEPTH (METRES)	VELOCITY (M/SEC)
1.8	1458.9
3.3	1459.8
4.3	1460.2
5.6	1460.8
6.6	1460.5
7.9	1459.8
8.7	1458.9
10.8	1457.3
11.3	1458.6
11.9	1458.2
13.2	1457.3
14.3	1454.4
15.3	1450.3
16.4	1450.9
17.4	1449.4
18.5	1446.5
19.6	1446.2
20.7	1445.3
21.7	1445.3
22.7	1443.1
23.8	1441.5
25.1	1441.5
26.1	1444.6
27.2	1443.4
28.0	1444.0
29.3	1445.3
30.4	1443.4
31.6	1443.1
32.7	1444.3
33.5	1443.4
34.5	1445.3
35.7	1442.7
36.8	1443.1
37.9	1444.0
38.7	1442.4
40.2	1442.1
41.0	1443.1
42.0	1442.1
43.3	1442.8
44.4	1443.4
45.4	1442.1
46.2	1443.1
47.2	1443.7
48.6	1441.8
49.4	1442.1
51.0	1443.4
51.5	1442.8
52.5	1437.1
53.9	1438.4
54.5	1437.5
56.0	1437.1
56.8	1438.7

Figure 3. Hardcopy output from XSV Cast WA-022

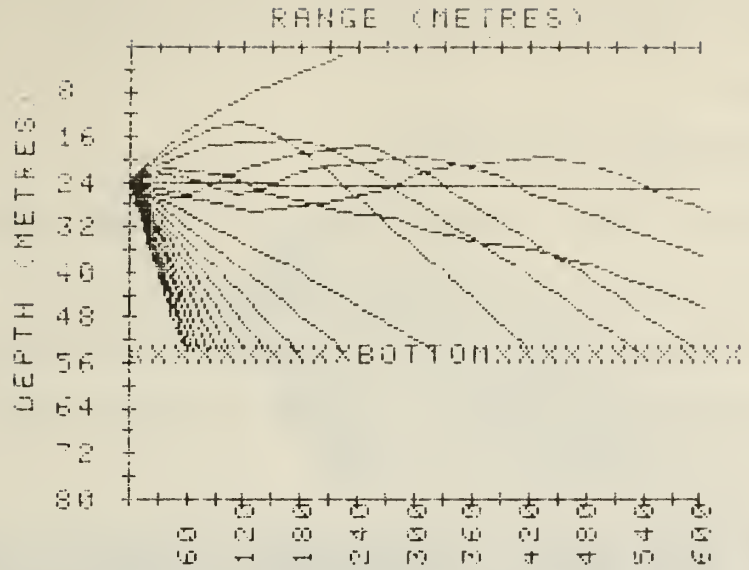


Figure 4. Ray-trace Diagram WA-022 (Fish at 24m)

In addition to providing information for determining an optimum tow depth and for confirming the extent of side-scan coverage, the ray trace plots were found to provide significant insight during the interpretation of the side-scan records. This can be readily shown by referring back to the velocity data recorded during XSV cast WA-022 and in particular to the associated ray-trace plot shown in Figure 4. Further examination of this plot reveals that, on the basis of the apparent refraction paths of the acoustic energy, the side-scan record should indicate:

- normal returns out to 200 metres
- some surface return from 180 to 220 metres
- weak returns (very nearly shadows) at 300 to 420 and at 420 to 540 metres (FALSE SHADOW)
- enhanced returns at 550 to 600 metres (FALSE TARGET)

The associated side-scan record, Figure 5, has the following, definite echo patterns which correlate well with the hypothesis derived from the ray-trace plots:

- normal returns to 150 metres
- mixture of surface returns (lloyds mirror type interference patterns) and normal returns from 150 to 350 metres
- very definite shadow region from 300-350 to 450-500 metres
- strong to medium clutter at 450-500 to 550-600 metres

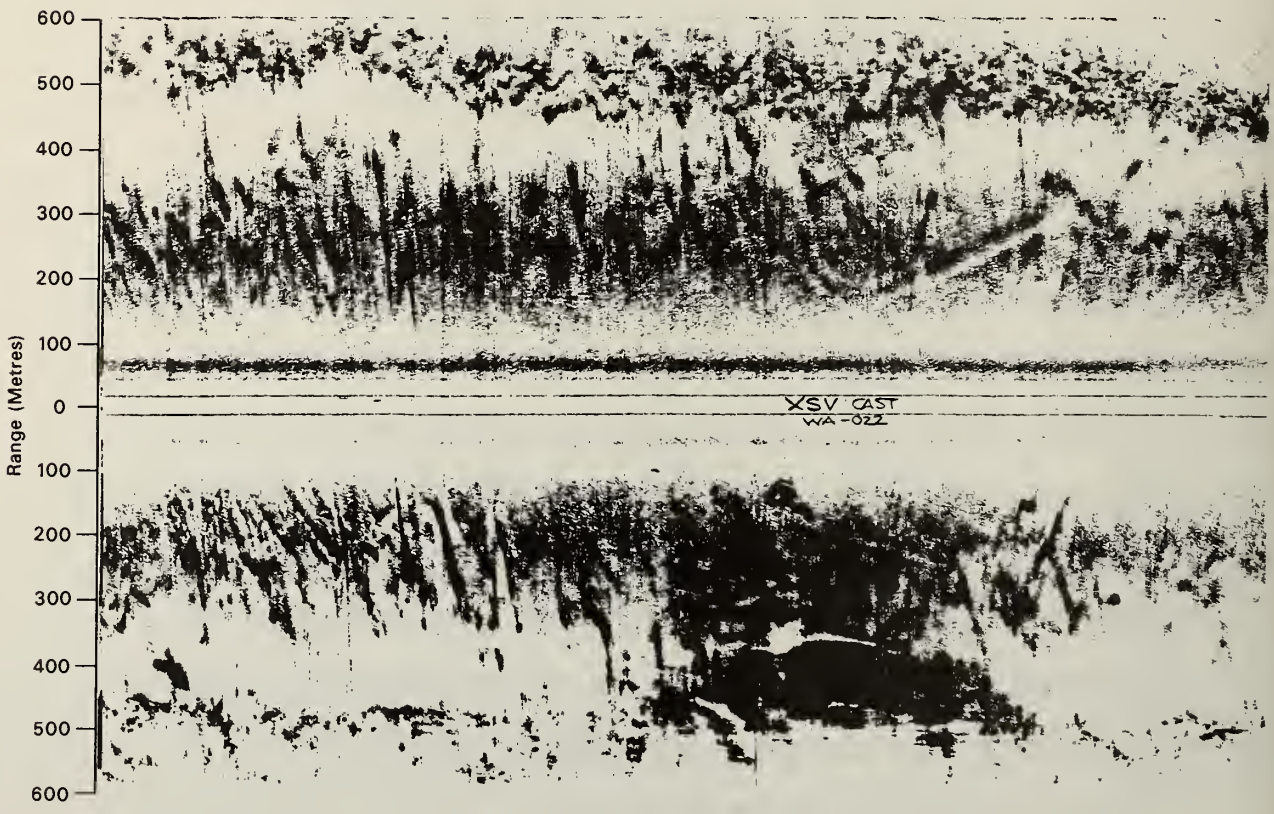


Figure 5. Side-scan sonar record coincident with XSV Cast WA-022

A second example WA-018, Figures 6 and 7 can be seen to exhibit this close relationship between the ray-trace diagram and the side-scan sonar records. The major points to notice in this data set are the minimal surface

returns and the very strong, apparent target at 350 to 400 metres.

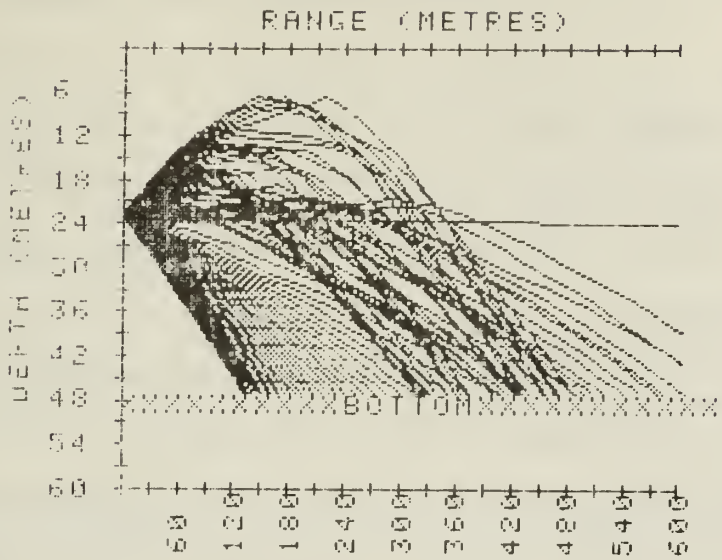


Figure 6. Ray-trace Diagram WA-018 (Fish at 23m)

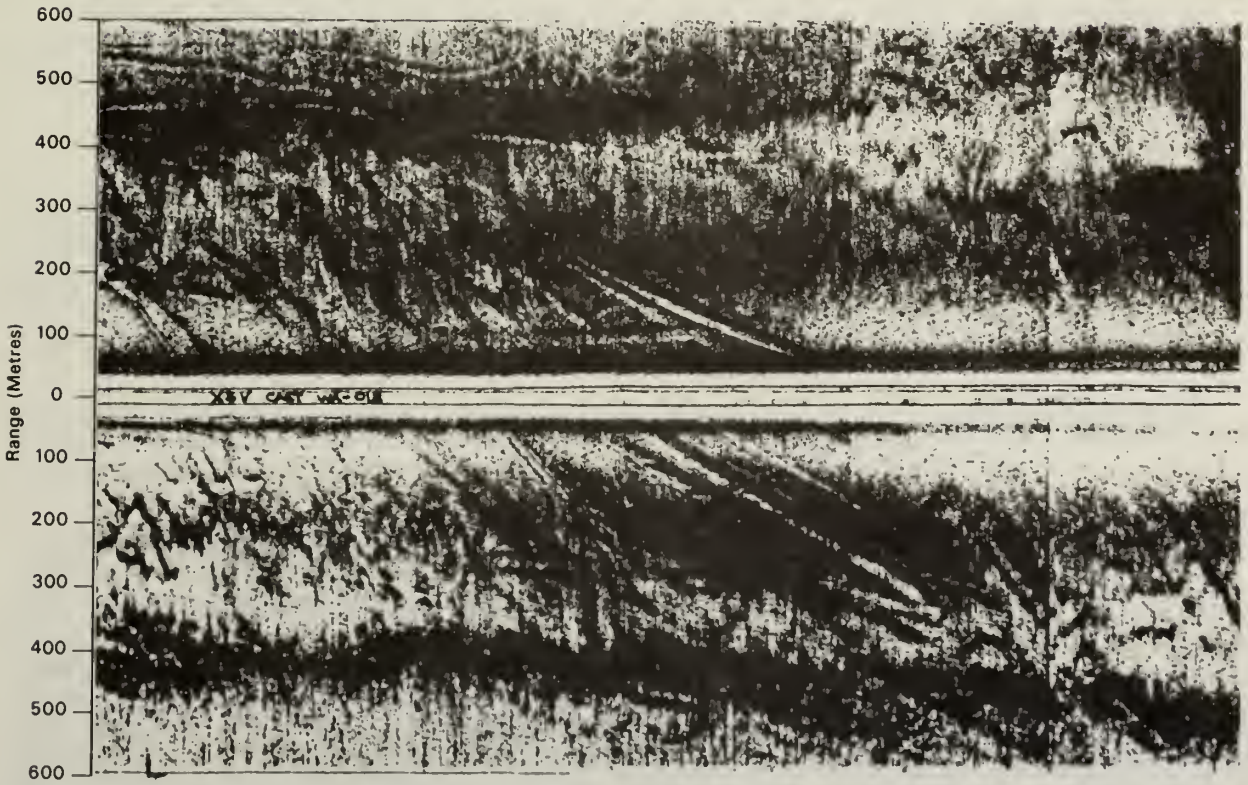


Figure 7. Side-scan record coincident with XSV Cast WA-018

CONCLUSIONS

The HP-85 based XSV deck unit developed at the Institute of Ocean Sciences effectively meets the hydrographic requirements for a sound velocity data acquisition and processing system. In addition to providing both hardcopy and magnetic tape cartridge records of the velocity data the system outputs, in near real-time, a sound velocity profile graph.

This sound velocity display system was also found to be a very effective, complementary tool in the performance of side-scan sonar sweep operations. It was effectively applied to determine the extent of side-scan coverage and was utilized as an interpretation aid to identify false targets which resulted from refraction focussing of the acoustic energy into reinforcement and shadow patterns. On the basis of the supporting field results obtained using this equipment in the Western Arctic I strongly recommend the application of this technique and the resultant ray-trace diagrams to all side-scan sonar operations.

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DISCUSSION

MR. WATT: If there are any questions, I would be pleased to entertain them.

CDR JOHN VANDERMEULEN, Officer of Marine Surveys and Maps: Two questions, please. One is it appears that the optimization of the water depth for the side scan sonar fish is a trial-and-error method at this point and that you just have to try different depths and watch the rate paths and try to find an optimum solution. If I am correct, do you have an intent of trying to introduce a software routine that would, in fact, find an optimum depth and tell you what that is for the condition observed?

MR. WATT: Again, to be brief, no. The intent right now is to use the system as it is, and in that fashion to use it in an iterative procedure just under operator control, having the operator select a different depth and take a look at the results.

CDR VANDERMEULEN: So I gather, then, that the main aid is the interpretation of the actual records that you achieve now and an explanation of what these records are?

MR. WATT: Of the ray trace records, or of the side scan records?

CDR VANDERMEULEN: The interpretation of the side scan records, knowing what the ray paths are.

MR. WATT: Okay.

CDR VANDERMEULEN: The other question I had: If I'm not mistaken, the decline recording mechanism is essentially a timed process from the center out, constant time. It seems to me -- and perhaps I hope I'm mistaken -- that when you say there is refractive focusing, obviously you are indicating that several of the rays are ending up at the same place on the bottom, according to the diagram, but many of the ray paths are longer or shorter with respect to each other.

So doesn't it seem that you would be looking for effects that result from the same time of the sound following any one of those ray paths, and that does not necessarily coincide at a range or place in the bottom?

MR. WATT: Okay. That's quite correct. I think the thing that I have to point out on those slides of the ray trace diagram, the horizontal scale was 600 meters. The vertical scale was in the order of 60 meters, I guess a ten-times stretching. And although there is a difference in the ray path length, it really isn't significant when you are talking about 50 meters. If you recall on the slide where it was focused to the one point, the upper rays might have been five meters to ten meters longer than the lower rays, so that you are still looking at the -- that's why I wasn't specific and said it would be at 520 meters. I said it would be around 500.

CDR VANDERMEULEN: All right. Thank you.

MR. WATT: Okay.

LCDR GERALD B. MILLS, NOAA Corps, Instructor at the Navy Postgraduate School, Monterey: I'm curious, have you done any testing on the XSV as far as its accuracy, say, compared to some other systems?

MR. WATT: Very little. We had done some back in, I think, about 1977. In 1978, the Davidson, out of Seattle, did some fairly extensive tests, and I don't know if a report was ever published. I have certainly seen their report. There was no author attached to it, but I have read the report, and it seemed to confirm what he had found, and that was that the XSV was not developed for hydrography; it was developed, if anything, for oceanography, and they were looking for a fairly high order of accuracy.

And I think, just to generalize, the accuracy that you can expect from the XSV is at least an order of magnitude greater than what a hydrographer is looking for.

LCDR MILLS: Also you mentioned the expense. How expensive are we talking about?

MR WATT: In Canadian funds, the XSV's will run about $120 apiece.

LCDR MILLS: Thank you.

LARGE SCALE SURVEYS WITH THE AGA GEODIMETER 120

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ABSTRACT: The distance to a moving vehicle can be measured very accurately with the AGA Geodimeter 120. This tracking ability makes the instrument useable for large scale hydrographic positioning. It is less expensive and more accurate than other electronic positioning systems; it has greater range and better accuracy than most traditional methods used for large scale work.

INTRODUCTION

For some time, the Canadian Hydrographic Service (CHS) has recognized the need for a high accuracy positioning system that may be used for large scale surveys. The recent acquisition of an AGA Geodimeter 120 will help fill this need.

The Geodimeter 120 is a shore range, light-weight instrument that fits conveniently on most theodolites and is moderately priced compared with other electronic positioning systems. This instrument uses infrared light for distance measurements and is equipped with a vertical angle sensor. It can measure vertical angles up to ±30 degrees and distances greater than 3 kilometres. These features make it a very useful survey instrument, but the most interesting feature from a hydrographic point of view is its tracking capability. The Geodimeter 120 can track at up to 4 metres per second or about 9 miles per hour. This capability allows the distance to a moving vehicle to be measured very accurately and at a relatively low cost.

The present methods used for positioning on large scale surveys are adequate for many requirements. Good results can be achieved up to 125 metres offshore with the subtense method used by the CHS. "Along line" position is determined by subtense measurements on a marked 4 metre board. The survey boat is kept "on line" by following ranges (or transits). However, the increasing volume of traffic and the large number of deep draught vessels has created requests for large scale surveys that cover greater areas than in the past. Lines more than a kilometre long can be run with the Geodimeter 120, thus giving high accuracy well beyond the limits of measurements made using a subtense board.

HISTORY

Traditionally, in the CHS, large scale surveys were carried out using very elementary equipment: the sounding lead, a measured wire or "stretch-line", range poles, and a dory. On the shore a baseline was established and ranges were set up perpendicular to the baseline. The oarsman kept himself on line by sighting a range and the leadsman took the depth. Distances off the baseline were determined by marks on the stretchline. An improvement on this method was the use of subtense measurements on a marked 4 metre board to determine distance off the baseline. This was much faster than "stretch-lining" and an echo sounder could be used for depth determination. At one point, experiments were carried out using a horizontally mounted sounder transducer to measure distances from a wharf face. This idea did not prove to be practical.

There are probably as many variations in carrying out large scale surveys as there are surveyors. These include combinations of sextant and theodolite positioning methods in combination with various electronic systems. As the areas of coverage increase, these methods require added manpower and time. Also, many electronic systems do not meet the accuracy requirements for large scale surveys. It is inefficient to be using equipment that could be used more effectively on smaller scale jobs.

USING THE AGA GEODIMETER 120

An AGA Geodimeter 120 (fig. 1) was purchased in March 1980 to be available for use during the field season. It proved to be very easy to operate. The instrument mounts on an adapter attached to the telescope of a theodolite and is connected to a small 12 volt battery which clips to the tripod. Atmospheric corrections for temperature and pressure are calculated in parts per million by a slide rule provided and easily dialed on the instrument. The operator has the option of selecting height difference, vertical angle, slope distance or horizontal distance. He can also select whether he wants one measurement, the mean of all measurements or the tracking mode. The telescope of the theodolite is pointed at the reflecting prism and the measuring button is pressed. The distance is displayed in a few seconds on the digital display.

A check of the geodimeter was carried out on the Halifax baseline. This baseline was established by Geodetic Survey of Canada using the Meko-

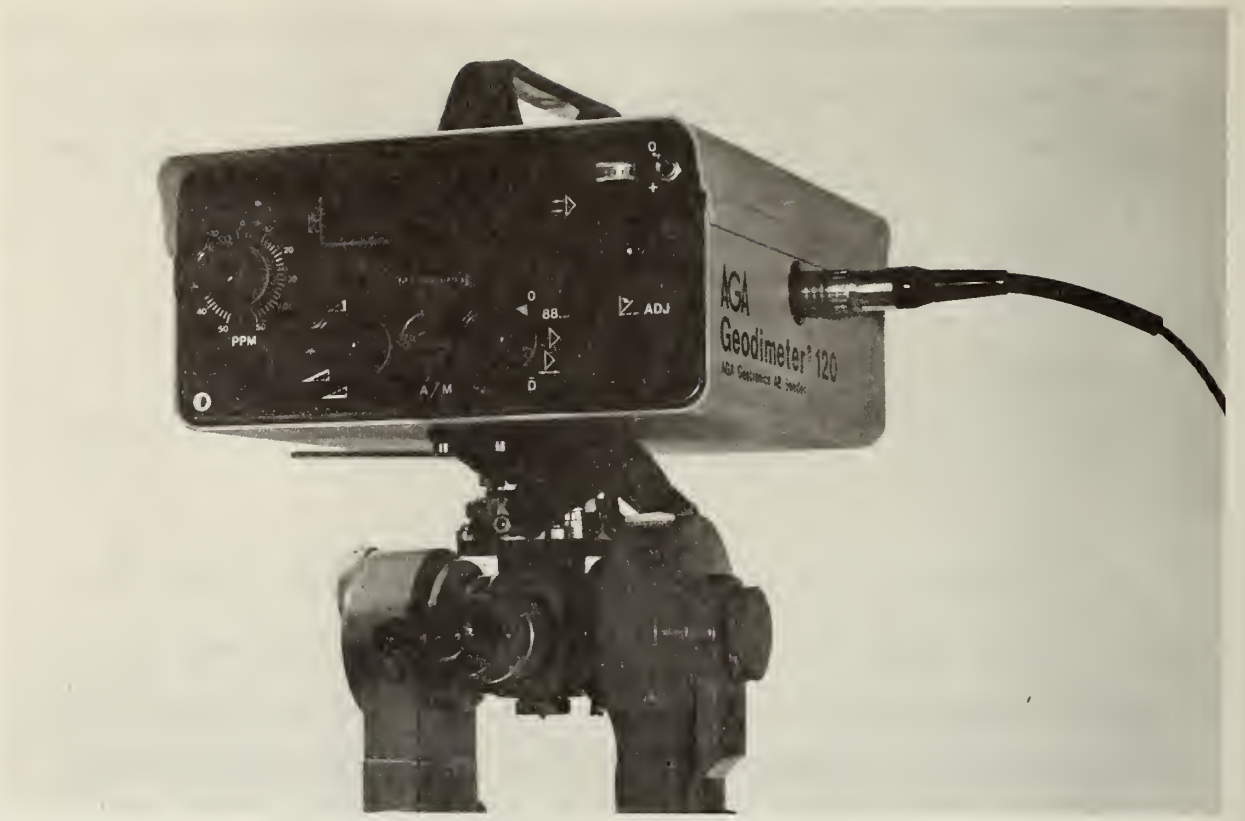

Fig. 1 AGA Geodimeter 120 mounted on Wild T-2 Theodolite

meter and spirit levelling. The geodimeter performed within specifications: ±(10 mm + 7 ppm) with internal mean calculation, ±(10 mm + 10 ppm) for normal measuring, and ±(20 mm + 10 ppm) in the tracking mode. Some preliminary tests were undertaken in order to determine a useable procedure for positioning a sounding launch. The instrument was placed on the launch and the reflector was set up on shore. This approach did not work because the narrow beam width of the geodimeter and the motion of the launch made pointing impossible.

The unit was then properly mounted on a Wild T-2 on shore and the reflector placed aboard the launch. The coxswain followed a range and steamed towards the shore. First, the instrument was pointed at the reflector without the aid of the T-2 telescope, but this gave poor results. By using the T-2 telescope to point the geodimeter, it was possible to follow the reflector to within about 60 metres of the wharf face where the setup was located. A closer approach was not possible due to the elevation of the wharf deck. The vertical angle to the reflector could not be changed fast enough with the tangent screw to keep a signal. In an attempt to create a larger, low cost reflecting surface, bicycle reflectors were used in place of the reflector prisms but range was limited to about 150 metres. These tests demonstrated that the Geodimeter 120 could be used to position a moving launch; it was now a matter of improving the methods.

For most large scale work, the sounding vessel is kept on line by having the coxswain follow a suitable range. When higher "on line" accuracy is required, the launch is conned from shore by theodolite.

It was decided to use the following procedure with the Geodimeter 120. The theodolite, with the geodimeter mounted, was set up ashore on the base-line, in line with the range for the sounding track. The desired angle was set on the theodolite and the coxswain brought the sounding launch on line using the ranges. Small corrections were then signalled or radioed to the boat as it approached shore. Sounding lines of at least one kilometre in length were possible. This method required extra care, good weather con-

ditions, and a competent coxswain. An opportunity to use the system in the field was provided by a survey of the approaches to the Canso Canal near Port Hawkesbury on Cape Breton Island, Nova Scotia. This survey, at a scale of 1/1200, specified sounding coverage to extend out to a depth greater than 15 metres, requiring most of the lines to be 200 metres long. Baselines were established, sounding lines were marked off and ranges were set up on wharves which extend from each end of the canal. This layout work was done using the Wild T-2 - Geodimeter combination. Time was saved during this part of the survey because short distances, required for site preparation, were measured without using a tape. Sounding lines 125 metres long were run using the conventional subtense method. These lines were extended to 200 metres in length with the Geodimeter 120 (fig. 2). The reflecting prism, mounted on a range pole, was attached to the side of the sounding boat, directly over the transducer of the sounder, a Raytheon DE719. The ranges were used as a guide for the coxswain. The personnel on the launch consisted of the coxswain, and a hydrographer to tend the sounder and keep notes. Two men were required on shore - one to tend the geodimeter and direct the launch, another to read the display and radio the fixes to the launch hydrographer at predetermined intervals. After the regular lines were run, check lines were run across the entire sounding area. Lines over 600 metres long were run without difficulty. When the soundings were scaled, excellent agreement was obtained at crossovers and where geodimeter lines overlapped conventional lines.

The Geodimeter 120 proved to be a useful tool; we were able to run long lines with relative ease. This instrument provided excellent accuracy

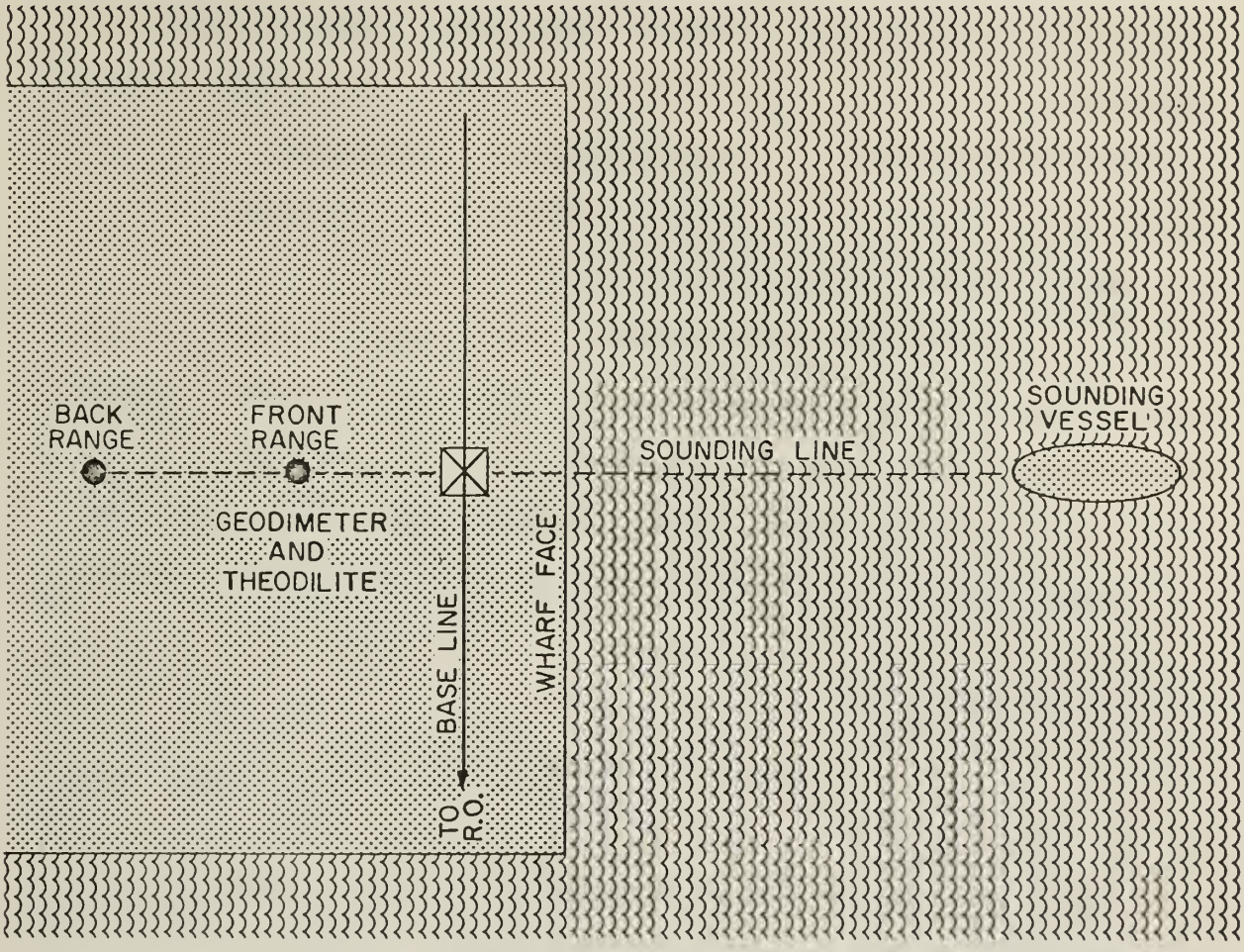

Fig. 2 Typical setup for a large scale survey

along the sounding line; when the sounding vessel moved "off line" more than the allowable error, it was rerun. Experience showed that a good coxswain could maintain ±2 metre accuracy with few course corrections radioed from shore, provided that good ranges were established.

When the AGA Geodimeter 120 is not being used as a positioning system, it is not sitting idle. It is excellent for large scale surveys of wharves,

buildings and the coastline itself - operations which have, to date, involved stadia distance measurements. The only restriction is the visibility of objects to be positioned. Stadia surveys with conventional methods require frequent setups, and the best accuracy possible is ±0.3 metres. The geodimeter is fast, very accurate, and with 3 prisms has a range from 0.2 to 2200 metres. Often all work can be done from one setup. Short traverses can be carried out quickly and accurately. The distances to elevated objects such as navigation lights can be measured simply by placing the reflecting prism on top of the object. This way there is no need for offsets; also, ground level obstructions are avoided. Placing a radio wave system on top of a light structure is difficult at best and impossible most of the time.

OTHER POSITIONING METHODS

There are a number of ways to position large scale surveys (fig. 3). Electronic positioning systems such as Mini Ranger, Trisponder, Artemis and Tellurometer MRD 1 may be used. All of these systems are very expensive compared with the Geodimeter, and only Artemis and Tellurometer will provide the accuracy required for most large scale surveys. In the CHS, large scale surveys are often done in small open boats, making the installation of electronic gear difficult and leaving the equipment open to the elements. The method of subtense measurements on fixed ranges works quite well; no expensive equipment is required and it is quick and easy to do. However, this method is only accurate for relatively short distances. Simultaneous horizontal sextant angles have parallax errors that become significant at

SOME POSITIONING SYSTEMS USED FOR LARGE SCALE SURVEYS

System	Approx. Cost (CDN $, 1980)	Accuracy	Comments
Artemis	$150K	Range ± 1.5m Arc ± 2 minutes	Subject to signal losses due to obstructions and competing transmissions.
Mini Ranger III	50K	± 3m with best geometry	
Trisponder	44K	± 3m	
Tellurometer MRD1	82K	± 1m	
Horizontal Sextant Angles	1K	± 3m	Fix interval too long.
Subtense and Ranges	1K	± 2m	Not accurate beyond 125m.
Stretchline	1K	± 2m	Time consuming; spot soundings only. Limited distance.
Theodolite Angles	15K	± 1m	Time consuming; fix interval too long.
Geodimeter 120 and Theodolite	17K	Range (± .2m) ± 1m "on line"	Time consuming

Fig. 3

large scales. Angles cannot be taken fast enough to properly control the sounding vessel. The old method of using a measured wire and ranges can be quite accurate if care is taken, but it is time consuming, limited in distance and only spot soundings are obtained. One of the most accurate methods of positioning is with simultaneous theodolite angles from control points on shore. This method requires communication between all persons involved and, as with sextant fixing, these fixes cannot be taken fast enough to properly control the launch. There are probably many other variations or combinations of the above methods. All have limitations in accuracy, speed or cost.

CONCLUSION

The AGA Geodimeter 120 as a positioning system is useable, but methods to improve its use will continue to be sought. "On line" control with a theodolite is time consuming and often frustrating for everyone involved. It may be possible to use sector lights or lasers to keep the sounding launch on line rather than using ranges and a theodolite. Having a radio controlled event marker on the launch would reduce the chance of time delay which occurs when calling a fix to the sounder man. Another way is to have a remote display on the boat. A major option available for the Geodimeter is the Geodat 120, a small data acquisition device. Fixes may then be called to the launch on a time basis. The distance and fix number will be stored in the Geodat with the push of a button. One person may then point the Geodimeter without the need for a second person to read the display and call the fixes at predetermined distances. Implementation of these ideas is possible in the future, but they will add expense to the system.

The AGA Geodimeter 120 and a theodolite combined with sensitive ranges will provide excellent accuracy at a relatively low cost. The main drawback is time consumption. All equipment has to be moved and set in place for each sounding line. If the launch drifts beyond the tolerance set for "on line" control, that line must be rerun. In cases where less accuracy will satisfy survey requirements, time spent can be reduced by using only the ranges for "on line" control. More work needs to be done before a system is perfected, but the AGA Geodimeter 120 can provide the basis for a relatively inexpensive and very accurate positioning system suitable for large scale surveys. When it is not used for sounding work, it pays its way as an excellent survey instrument on shore.

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DISCUSSION

MR. ROCKWELL: If anybody has any questions, I will make an attempt to answer.

LCDR MILLS: Gerry Mills, NOAA Corps Navy Postgraduate School: It seemed to me that you would be quite limited to fairly calm waters, if you had very much rough water that the prisms would be moving around quite a bit. Is that true in your experience?

MR. ROCKWELL: That's true. You have to have good weather conditions. The beam width is quite narrow, and if there is much movement of the prisms, then you'll have trouble.

LCDR MILLS: Does it have to be basically flat calm?

MR. ROCKWELL: Not flat calm, no. We worked in just a light chop, ten-mile-an-hour breeze, that sort of thing, where it's relatively sheltered. Doesn't have to be flat calm.

LCDR MILLS: Thank you.

MR. ROCKWELL: Thank you.

The Hydrography Program at the Naval Postgraduate School

by

LCDR Gerald B. Mills, NOAA
Naval Postgraduate School - Code 68 Mi
Monterey, California 93940

ABSTRACT

The Oceanography Curriculum (Hydrography Option) at the Naval Postgraduate School (NPS) is discussed. Course descriptions and requirements for the Master of Science degree are presented. The NPS program satisfies the majority of the requirements for Category A Hydrographic Surveyor as prescribed by the International Hydrographic Organization (IHO) and the International Federation of Surveyors (FIG) in the "Standards of Competence for Hydrographic Surveyors".

The Naval Postgraduate School (NPS) is located in Monterey, California, 120 miles south of San Francisco. It was established in 1909 at Annapolis, Maryland and moved to the grounds of the former Del Monte Hotel in Monterey in 1951. There are approximately 1150 students presently enrolled in the various curricula at NPS. These students are military officers of the United States and allied countries, NOAA Corps officers and U.S. government civilian employees.

Of the seventy students enrolled in the Environmental Sciences, eleven are pursuing a Master of Science degree in Oceanography (Hydrography). The hydrography option integrates the scientific principles of oceanography with the practical engineering procedures of hydrography. Prerequisite to entering the program is a baccalaureate degree or equivalent with above average grades in mathematics and the physical sciences. In addition,

differential and integral calculus, one year of college physics, and one year of college chemistry are required.

The course sequence for the hydrography option is shown in Table 1. These courses are divided into four general groups: (1) preparatory courses, (2) basic physical and dynamical oceanography, (3) analysis and forecasting and (4) mapping, charting and geodesy. Brief descriptions of the courses in each group are presented below. The numbers in parentheses show the number of lecture hours and laboratory hours per week.

(1) Preparatory Courses:

CS 2810 Fortran Programming (3-2) - An introduction to computer algorithms, programs and hardware. Algorithms and programs are developed using a structured approach to stepwise refinement of algorithms. Computer systems including data representation, computer organization and systems software. The solution of scientific and engineering problems using structured FORTRAN is studied.

MA 2047 Linear Algebra and Vector Analysis (4-0) - Solutions of linear systems of equations, algebra of matrices, determinants. Linear vector spaces, linear dependence and independence, subspaces, bases and dimension. Inner products, ortho-normal bases and Gram-Schmidt process. Eigenvectors and eigenvalues. Del operator, directional derivative, gradient, divergence and curl with applications. Line, surface and volume integrals, Green's, Stoke's and divergence theorems.

MA 2121 Differential Equations (4-0) - Ordinary differential equations: linear and non-linear equations, homogeneous and nonhomogeneous equations, linear independence of solutions, power series solutions, systems of differential equations, Laplace transform applications.

MA 3132 Partial Differential Equations and Integral Transforms (4-0) - Solution of boundary value problems by separation of variables; Sturm-Lionville problems; Fourier, Bessel and Legendre series solutions, Laplace and Fourier transforms; classification of second order equations; applications.

(2) Basic Physical and Dynamical Oceanography:

OC 3120 Biogeochemical Processes in the Ocean (4-3) - Basic biological, geological and chemical processes in the ocean. Bioacoustics, deep scattering layers and bio-deterioration. Geomorphic features of the ocean floor; kinds and distribution of ocean bottom features. Chemical composition of the ocean; molecular level influences on sound attenuation, non-acoustic

TABLE 1
24-3

OCEANOGRAPHY CURRICULUM (HYDROGRAPHY OPTION)

QTR					HOURS
1	Physical Oceanography OC 3220 3-3	Fortran Programming CS 2810 3-2	Differential Eqns MA 2121 4-0	Linear Alg & Vectors MA 2047 4-0	14-5
2	Analysis Exp Data PS 2350 3-1	Air-Ocean Fluid Dyn OC 3321 4-0	MC&G OC 3901 4-2	Partial Diff Eqns MA 3132 4-0	15-3
3	Biogeochemical Process in the Ocean OC 3120 4-3	Ocean Circ Analysis OC 3221 4-0	Marine Geophysics OC 3325 3-0	Hydro and Geod Survey OC 3902 3-3	14-6
4	Dynamical Oceanography OC 4211 4-0	EM/EO Propagation OC 3xxx 4-0	Physics of Sound Ocean PH 3431 4-2	Photog & Remote Sensing OC 4908 3-2	15-4
5	Hydrographic Cruise OC 3909 0-4	Geom & Astro Geodesy OC 4906 4-0	Hydrographic Meas OC 3904 3-2	#Elective 4-0 *Thesis Research OC 0810	7-6
6	Hydrographic Operations OC 3905 3-2	Tides OC 4212 3-0	Grav&Satellite Geodesy OC 4907 4-0	# *Thesis Research OC 0810	10-2
7	Coastal Oceanography OC 4213 3-2	Elective	Elective	#Thesis Rch OC 0810 *Thesis Rch & Semnr OC 0810 & OC 0999	10-2 (EST)
8	#Elective	#Elective	#Elective	#Thesis Research #Thesis Seminar OC 0810 & OC 0999	10-0 (EST)

NOTE: * Seven Quarter Student, # Eight Quarter Student

ASW and other applications.

OC 3220 Physical Oceanography (3-3) - Physical properties of sea-water. Processes influencing the distribution of heat, salt and density in the ocean. Wind-driven and thermohaline components of the oceanic general circulation.

OC 3321 Air-Ocean Fluid Dynamics (4-0) - Development of the hydro-dynamical equations in a rotating fluid, forces acting on fluids; stream function, velocity potential, geostrophic, gradient and inertial flows; baroclinic and barotropic fluids, vertical variation of horizontal velocity; Ekman spiral applied to ocean and atmosphere; geopotential surfaces, level of no motion; vorticity and divergence equations.

OC 4211 Dynamical Oceanography (4-0) - Linear theory of surface and internal waves; theory of finite amplitude waves; windwave spectra. Inertial-internal, Rossby and Kelvin waves.

PH 3431 Physics of Sound in the Ocean (4-2) - A survey of physical acoustics with emphasis on the generation, propagation and detection of sound in the ocean. Topics include: damped and forced harmonic oscillations; the acoustic wave equation and its limitation in fluids; solutions for plane and diverging waves; ray acoustics; radiation of sound; reflection from boundaries; term by term analysis of the SONAR equations emphasizing trans-mission loss models and detection threshold models; properties of transducers for underwater sound.

(3) Analysis and Forecasting:

PS 2350 Analysis of Experimental Data (3-1) - Introduction to statistical analysis of measurements and experimental data. Frequency distributions, graphical representations. Populations and sampling. Principle of least squares, estimation of mean and standard deviation. Curve fitting and regression, propagation of errors. Confidence intervals, tests and contingency tables.

OC 3221 Ocean Circulation Analysis (4-0) - Ekman dynamics and flow properties. Geostrophic dynamics and flow properties. Conservation of potential vorticity. Sverdrup transport. Western intensification. Use of satellite altimetry in dynamic calculations.

OC 3xxx Electromagnetic and Electro-Optic Propagation (4-0) - Presently under development but will include properties of electromagnetic and electro-optic wave propagation and the phenomena of radio and radar trans-mission including special topics on antennas and waveguides.

OC 4213 Coastal Oceanography (3-2) - Shoal-water wave processes, breakers and surf; nearshore water circulation; beach characteristics; littoral drift; coastal hydraulics, storm tides.

(4) Mapping, Charting and Geodesy (MC&G):

OC 3325 Marine Geophysics (3-0) - Theory and methods of marine geophysics surveys, and emphasis on gravity, magnetic, seismic and acoustic wave propagation, heat flow, and radioactivity.

OC 3901 Mapping Charting and Geodesy (4-2) - Principles and fundamentals of geodesy, photogrammetry and cartography. The application of these disciplines to mapping and charting with emphasis on the propagation of random errors inherent in each phase of the mapping and charting process; data collection data reduction, generalization, and protrayal.

OC 3902 Hydrographic and Geodetic Survey (3-3) - Principles and fundamentals of hydrographic surveying and support methods from the field of geodetic surveying. Introduction to survey procedures, both at sea and on land including use of surveying instruments.

OC 3904 Hydrographic Measurements (3-2) - Measurements required in hydrographic surveying and necessary corrections to those measurements. Sources of error. Hydrographic data interpretation, reduction, presentation and quality evaluation. Critical analysis of specific hydrographic survey techniques and methods.

OC 3905 Hydrographic Operations (3-2) - Hydrographic survey project planning and management. Selection of appropriate methods and equipment including a survey of contemporary hydrographic measurement systems.

OC 3909 Hydrographic Cruise (0-4) - Field activities in hydrographic survey support, data acquisition and reduction, and data presentation.

OC 4212 Tides (3-0) - Development of the theory of tides including the tide-producing forces, equilibrium tides, and the dynamic theory of tides; harmonic analysis and prediction of tides; tidal datum planes and their relationship with geodetic datum planes, short-term and secular changes in sea level.

OC 4906 Geometric and Astronomic Geodesy (4-0) - Properties of the ellipsoid, geometric aspects of geodesy including triangulation, trilateration, traverse and leveling techniques and instrumentation; adjustment by lease squares, astronomic determination of latitude, longitude and azimuth; time and astronomic instrumentation.

OC 4907 Gravimetric and Satellite Geodesy (4-0) - Potential theory as applied to the gravity field of the earth; application of Stokes' Formula, integral, and function; deflection of the vertical; gravimetric reduction; geometric and dynamic application of satellites, orbital geometry and satellite orbit dynamics.

OC 4908 Photogrammetry and Remote Sensing (3-2) - Application of photogrammetric instruments and techniques to planimetric, topographic and hydrographic data compliation. Use of analog, semi-analytical, and analytical photogrammetry in geodetic control extension. Planning and

execution of aerial photography. Principles and fundamentals of remote sensing. Application of remote sensing imagery to mapping and charting.

Elective courses are available in satellite oceanography, ocean operations, meteorology, computer science, ocean policy or management. An acceptable thesis on a topic approved by the Department Of Oceanography is also required for the degree Master of Science in Oceanography (Hydrography).

The instructors for the courses in mapping, charting and geodesy are shown below. Professor von Schwind is a permanent faculty member while LCDR Leath and LCDR Mills are temporarily assigned and will be replaced at the end of their tours of duty.

JOSEPH J. von SCHWIND, Associate Professor Oceanography and Geodetic Sciences, 1967

B.S., Chemical Engineering, University of Wisconsin, 1952
M.S., Geophysics, University of Utah, 1960
Ph.D., Physical Oceanography, Texas A&M University, 1968

Responsibilities: Geometric and Astronomic Geodesy, Gravimetric and Satellite Geodesy, Marine Geophysics, Tides

GERALD B. MILLS, Lieutenant Commander, NOAA, Instructor in Hydrography, 1980.

B.A., Mathematics, Washington State University, 1967
M.S., Oceanography (Hydrography), Naval Postgraduate School, 1980

Responsibilities: Hydrographic and Geodetic Survey; Hydrographic Cruise, Measurements and Operations.

DUDLEY W. LEATH, Lieutenant Commander, USN, Instructor in Photogrammetry/ MC&G, 1979.

B.S., Oceanography, U.S. Naval Academy, 1970
M.S., Applied Ocean Sciences, University of California at San Diego, 1974

Responsibilities: Photogrammetry and Remote Sensing, MC&G, half time.

An application is being prepared for certification of the NPS hydrography program as one that meets the requirements for Category A Hydrographic Surveyor. The criteria for this certification appears in the paper "Standards of Competence for Hydrographic Surveyors" which was approved by the International Advisory Board (consisting of members of the IHO and FIG) in February 1978. A brief outline of the requirements for Category A certification and the NPS courses which satisfy them (at least in part) are shown below.

(1) Mathematics, Mechanics and Statistics

1.1	Calculus	Prerequisite
1.2	Series	MA 2121, MA 3132
1.3	Matrix Algebra	MA 2047
1.4	Complex Variables	MA 2121
1.5	Co-Ordinate Geometry	MA 2047
1.6	Spherical Trigonometry	OC 3901, OC 4906
1.7	Mechanics	Prerequisite
1.8	Statistics	PS 2350, OC 3904, OC 4906

(2) Measurement Science - Theory

2.1	Units of Measure	Prerequisite
2.2	Oscillatory Mechanics	Prerequisite plus PH 3431
2.3	Electricity and Magnetism	Prerequisite plus OC 3xxx
2.4	Electronics and Radio-electricity	Prerequisite plus OC 3xxx
2.5	Underwater Acoustics	PH 3431
2.6	Optics	Prerequisite, OC 4908, OC 3xxx
2.7	Remote Sensing	OC 4908
2.8	Measurement Technology	OC 3904

(3) Measurement Apparatus and Systems

3.1	Measurement	OC 4906
3.2	Angular, Directional and Distance Measuring Instruments	OC 3904, OC 4906
3.3	Marine Electronic Positioning Systems	OC 3902, OC 3904, OC 3905
3.4	Acoustic Systems	OC 3902, OC 3904, OC 3905, PH 3431
3.5	Oceanographic Instrumentation	OC 3220, OC 3902, OC 3904, OC 3905
3.6	Marine Geophysical Measurements	OC 3325

(4) Automated Data Gathering and Processing

4.1	Introduction to Computers	CS 2810
4.2	Use of Computers and Calculators	None
4.3	Use of Plotting Systems	None
4.4	Use of Digitizing and Automated Data Logging Systems	None
4.5	Integrated Processing/ Control Systems	None
4.6	Data Recording Units	None
4.7	Systems Design for Particular Applications	None

(5) Environmental Science

5.1	Oceanography	OC 3120, OC 3220, OC 3221, OC 4211, OC 4213
5.2	Tides (a) Concepts	OC 4212
	(b) Tidal Currents	OC 3904 and OC 4212
5.3	Geology and Geophysics	OC 3120, OC 3325
5.4	Gravity and Magnetism	OC 3325

(6) Terrestrial Surveys

6.1	Geodesy	OC 3901, OC 4906
6.2	Horizontal Control	OC 3902, OC 3904, OC 4906
6.3	Vertical Control	OC 3902, OC 3904, OC 4212, OC 4906
6.4	Astronomy	OC 4906
6.5	Photogrammetry	OC 3901, OC 4908

(7) Marine Surveys

7.1	Determination of Position	OC 3902, OC 3904, OC 3905, OC 3909
7.2	Track Control	OC 3902, OC 3904, OC 3905, OC 3909
7.3	Determination of Depth	OC 3902, OC 3904, OC 3905, OC 3909
7.4	Hydrographic Surveys	
	(a) Sounding Surveys	OC 3902, OC 3904, OC 3905, OC 3909
	(b) Sweeping Surveys	OC 3902, OC 3904
	(c) Airborne and Satellite Techniques	OC 3905, OC 4908
	(d) Coastal Topography Aids and Navigational Pubs	OC 3902, OC 3904
7.5	Cartography	OC 3901, OC 3902, OC 3904, OC 3905, OC 3909
7.6	Geological and Geophysical Surveys	OC 3325
7.7	Physical Oceanography	OC 3220, OC 3902, OC 3904, OC 4212
7.8	Drafting of Reports Survey	OC 3905

(8)	Law of the Sea	NS 3901 (elective)
(9)	Nautical Science	
9.1	Navigation	None
9.2	Meteorology	MR 2210 (elective)

Recommended but not Required for Certification

I. Nearshore Surveying

I.1	Coastal Engineering	
	(a) Siltation and Erosion	OC 3120, OC 4213
	(b) Coastal Zone Management	OC 4213
	(c) Design and Construction of Harbor Works	OC 4213
	(d) Improvement	OC 4213
	(e) Removal and Dispersal of Wrecks	None
	(f) Channel Marking	None
I.2	Legal Aspects	None
I.3	Position Fixing	OC 3904, OC 3905
I.4	Tidal Aspects	OC 4212, OC 4213
I.5	Large Scale Surveys	OC 3905
I.6	Special Purpose Surveys	None

II. Offshore and Oceanic Surveying

II.1	Planning	None
II.2	Effects of the Elements	None
II.3	Oceanographic Equipment	OC 3220, OC 3904
II.4	Tidal and Current Measurements	None
II.5	Pollution Studies	None

Adjustments are being made in the program to fully satisfy all the academic criteria for Category A certification. An additional requirement which must be met is two months of supervised sea training.

Two classes consisting of sixteen students have graduated from the NPS

hydrography program since its inception in 1977 - 7 NOAA officers, 3 NAVOCEANO civilians, 3 DMAHTC civilians, 2 Portuguese officers and 1 Turkish officer. Thesis topics have included the following: water transparency for laser bathmetry applications, analytical modeling of hydrographic surveys, use of historical data for determining echo sounding velocity corrections, evaluation of dual beam with sounding systems, the applications of LORAN-C and Global Position System (GPS) receivers to hydrographic surveying, error analysis of hydrographic positioning including horizontal sextant angles, calibration methods for electronic positioning systems, the precision of tidal datums and the determination of land elevation changes using tidal data. Attendees of this conference are invited to forward suggestions for future thesis topics to NPS.

DISCUSSION

LCDR MILLS: I will be glad to entertain any questions there might be about the program.

No questions?

(Applause)

THE ROYAL NAVY'S HYDROGRAPHIC DEPARTMENT

Lt. Cdr. Thomas W. Richards
Exchange Officer
UK/NOS Hydrographic Exchange Program

ABSTRACT. The British Hydrographic Department produces a worldwide series of nautical charts and sailing directions. The organizational structure and the techniques used by the Royal Navy (RN) to gather and publish this hydrographic information are in many ways similar to that of the United States' National Ocean Survey (NOS). However, in a few very significant ways--such as the extensive British use of side scan sonar--they differ. This paper discusses the organizational and procedural similarities and differences between the RN's Hydrographic Department and NOAA's NOS.

The purpose of my presentation is first to relate to this conference my perception of the British Hydrographic Department's organization and secondly to introduce some of the techniques in use by the Royal Navy (RN) in conducting its hydrographic surveys throughout the world. This view of the British hydrographic surveying organization and its operations results from my recent 6-month tour of duty with the RN, both ashore and at sea, from June to December 1980.

The Hydrographic Department is organizationally located within the British Ministry of Defence and is administered by the RN. Ashore, the department is totally under the direction of the Hydrographer of the Navy, Rear Admiral D. W. Haslam. In operation of its ships the department has a dual chain of command. Logistical operation and maintenance of the ships comes under the direction of Commander in Chief Fleet (CINCFLT) through various area Flag Officers. The direction for the survey program afloat comes from the Hydrographer of the Navy.

The main shore facilities of the Hydrographic Department are situated in three geographic areas: Taunton, London, and Plymouth. Suprisingly, the Hydrographic Center of Taunton is located in the hilly countryside of southwest England. The Hydrographer maintains an office in both London and Taunton, splitting his time between both locations during any given week. The third area facility is the RN's school of hydrographic surveying located in Plymouth.

The RN's Hydrographic Office is located in Taunton. This office is separated into three divisions: the Plans and Surveys Division, the Charting and Sciences Division, and the Administration and Supply Division.

The Plans and Surveys Division, also called the Naval Division, directs and plans the survey vessels' hydrographic projects and is in charge of

compiling information for the Admiralty Notice to Mariners, the Sailing Directions series, the Tide Tables, and the world coverage Light List.

There are three sections within the Naval Division that are very similar to NOS units and two are quite different. As an example, the RN's Survey Planning section performs essentially the same functions as the NOS Hydrographic Surveys Division in drafting Hydrographic Instructions (HI's), monitoring hydrographic surveying operations, and maintaining quality control of survey data.

The Sailing Directions Office is analogous to NOS' Coast Pilot Branch. It differs somewhat in that the Admiralty series of Pilots has worldwide coverage whereas NOS Coast Pilot covers only U.S. waters. Their publication is hard bound and is updated via supplement. Sailing Directions are reprinted approximately once every 12 years. In order to more rapidly correct this series of publications the British are evaluating whether they should change their format to conform to the Defense Mapping Agency (DMA) looseleaf system, choose the NOS frequent reprint system, or remain with the supplement system with additional Notice to Mariners. Incidentally, the Sailing Directions office has recently published a new detailed and well-written instruction booklet for survey units which explains how to take useful photographs for use in Sailing Directions. I will be receiving a copy soon, if anyone might be interested in seeing it.

The Tidal Branch within the Hydrographic Office is very similar to the three branches within the NOS Office of Oceanography: Marine Predictions, Tidal Analysis, and Circulatory Surveys. It differs, however, in that much of the data-gathering work is shared with other British Government agencies. Many of the tide gages are operated by the British Agriculture Department. Storm surge information is disseminated from Brackwell near London by the Naval Oceanography and Meteorology Directorate (DNOM). This directorate is not only concerned with issuing warnings of predicted dangerous high water situations but also often issues warnings to mariners of unusually low water to ensure that shipping does not run aground. The Tidal Branch relies on the British Ordinance Survey for geodetic leveling between tidal bench marks at the various long-term tide stations. It is interesting to note that the British have chosen to portray tidal current information directly on the nautical chart. This relieves many mariners of the need to buy tidal current tables.

The two sections within the Naval Division that differ considerably from offices in NOS are Taunton's Notice to Mariners Section and its Light List Office.

The Notice to Mariners Section issues both Radio Navigational Warnings and weekly printed Notice to Mariners. The same individuals that gather the information for the Radio and Weekly Notices also draft chart corrections onto British Admiralty charts. Much information not worthy of a notice, but affecting the chart, is regularly routed to the proper chart compilation section at Taunton for subsequent charting action. This Notice to Mariners function in the U.S. is handled by the U.S. Coast Guard (USCG) and DMA.

Also within this Notice to Mariners Section is located the RN's Wrecks Officer. The Wrecks Officer maintains a comprehensive listing of all charting information available on the thousands of wrecks in British home waters and selected foreign waters. This type of wreck information is frequently requested and paid for by salvage firms, recreational divers, historical groups, and fishermen. This wreck information has also been useful to the survey fleet in planning and carrying out investigations of wrecks as well as allowing for more definitive recommendations to be made by both hydrographers and compilers.

The second office within the Naval Division to which NOS does not have a counterpart is that of the Light List Office. Again, this function in the U.S. is performed by the USCG. The placement of this office in the Hydrographic Department in Britain readily allows all information concerning lights to be made consistent between the Light List and the nautical chart. Establishing and maintaining lights, buoys, and fixed aids to navigation, however, is not a function of the Hydrographic Department. Three organizations in the British Isles perform the majority of this function. They are Trinity House for English and Welsh coasts, Northern Lighthouse Board for Scotland, and the Irish Lighthouse Commission for all of Ireland.

A second division at Taunton is the Charting and Sciences Division, frequently referred to as the Professional Division. It performs the major functions of chart compilation and chart maintenance as well as providing technical support functions for the office and for survey operations.

Within this division are the Nautical Chart (NC) branches numbered NC-1 through NC-10. These branches are responsible for compiling and maintaining charts in specific areas of the world. As an example, NC-1 is responsible for British Home Waters; NC-4 is responsible for South America, Africa, and the Persian Gulf, and NC-7 is responsible for North America and the West Indies. NC branches have from 12 to 20 employees per branch.

All compilation undertaken by the NC branches on new editions of charts is metric compilation. The RN is much further ahead and more committed to metrication than NOS. In addition, there are two metric compilation sections NC-9 and NC-10. These branches are just now completing recompilation of the area surrounding Japan and will shift next to Southeast Asia metrication. Routinely, metrication of a chart takes 2 years from the beginning of compilation to issuance of the new metric chart. In an emergency it can be done in a matter of weeks but this results in disrupted production schedules.

The Hydrographic Office maintains a series of 3,500 different charts yielding worldwide coverage. One thousand of these charts have been metricated in the past 12 years, and it is hoped that by 1995 all 3,500 will be metric. Each chart that is published is kept current by hand correction for all British Admiralty Notice to Mariners to its date of sale.

Also located within the Professional Division at Taunton are the Marine Sciences (MS) branches which in general provide technical support to the cartographers, hydrographers, and oceanographers in the Hydrographic Department.

As an example, MS-8 is the group in charge of automating as many of the data acquisition and data compilation procedures as can be shown to be cost effective. At present the Hydrographic Department does not accept digital depth data directly in the field in lieu of analog depth data. This is a significant obstacle to total automation of the U.K. surveying and charting process. Final submission of field survey data is in the form of a manually produced "fair sheet." Hydrographic data tapes do not as yet come off the ships as smooth, processed data. Hydrographic data tapes do, however, come off the ships in their rough data logger format. The British do not believe that it is presently cost effective to totally digitize their survey data base.

The Hydrographic Department believes it is only cost effective for this group to automate portions of the British chart production process. Manually compiled and drafted charts are digitized on digitizing tables at Taunton. These digitized compilation diagrams are then checked and corrected through the use of an interactive computer to create a high quality graphic of the chart on a flatbed plotter. This high quality graphic can then be used to photographically produce the production printing plates for chart production.

Oceanographic data leaving the ships, such as gravity data, are processed in a totally automated manner, and automated plots of these data are routinely produced for the RN by MS-8.

MS-1 is the Professional Division support section responsible for providing the hydrographic survey units with geodetic information and reviewing the third-order geodetic data established by the field units. First-order basic control surveys are not accomplished by the Admiralty. The British Ordnance Survey Office is responsible for conducting basic control surveys in Britain. The Admiralty does, however, frequently conduct third-order surveys to establish control in support of hydrographic surveys. The horizontal control datum in Great Britain is the 1936 Ordnance Survey Datum, and positions are normally computed in Home Waters on a transverse Mercator projection. Vertical chart datum was recently changed on British charts to Lowest Astronomic Tide where it had been Mean Low Water in the past.

MS-5 is Taunton's Sedimentation and Photogrammetry Section. The aircraft used to fly photogrammetry in support of hydrography are the Ocean Survey Ships' WASP helicopters. The sedimentation group is involved in analysis of dredging operations in various estuaries in Britain.

The third and final division of Taunton is the Administrative and Supply Division. The major function of this division is the production and sales of the Admiralty's 3,500 nautical charts. The chart production and sales are operated on a commercial cost basis. Sales of the charts must cover the cost of producing the charts. During the first half of 1980 the Hydrographic Office had sold nearly 1-3/4 million charts worldwide.

One of the chart production problems faced by the British results from their policy of correcting all charts for Notice to Mariners subsequent to printing of the chart and prior to its sale. As a result of this policy, it is not possible to make large production runs of a given chart. To attempt

to manually maintain a very large stock of a given chart would not be cost effective. It is cheaper to make frequent additional production runs using revised printing plates. As a result, much of the time on the printing presses is spent in set-up or tear-down of a production run. Chart agents for British Admiralty charts that hold stocks of charts are also required to hand correct charts prior to sale. The British firmly believe these costs are worthwhile in order to provide the mariner with a chart that is corrected to the date of sale.

The remainder of the Administration and Supply Division performs the routine finance, personnel, training, and procurement fuctions for the Taunton facility.

The Hydrographic Department operates another but much smaller office in the Old War Office Building in London at Whitehall. In London are located one of RADM Haslam's personal offices; the office of the Assistant Hydrographer, Captain Hope; and DNOM. A small chart corrections office is also located here which provides the London Ministry of Defence offices with up-to-date charts and cartographic services.

Under the direction of the Assistant Hydrographer is the Territorial Waters Office which is involved in the negotiation and determination of international seaward boundaries. Also under his direction is the Hydrographic Information Office which handles public relations for the department. Although not located in London, the hydrographic training facility at Drake also comes under the direction of the Assistant Hydrographer.

The DNOM is the RN office that operates the Brackwell Storm Tide Warning Service. This directorate also carries out the Navy's oceanographic and meteorological research programs.

The RN's School of Hydrographic Surveying is located in Plymouth at HMS Drake. British Navy shore facilities such as Drake carry the title HMS as well as do Her Majesty's ships. At HMS Drake the RN trains the enlisted survey recorders (SR) and the seaman officers specializing in hydrography, nicknamed "Droggies."

The SR's perform tasks analogous to NOS survey technicians. These SR's train for approximately 2 to 3 months at Drake prior to each advancement in rate. In addition, the SR's complete an on-the-job task book while at sea, ensuring that they have acceptably performed all pertinent duties at least once.

The seaman officers attend Drake's Hydrographic School for a "basic" 2-month course, a more advanced "long" 6-month course, and a "final" 7-week course just prior to becoming Charge Hydrographic Surveyors.

The maintenance and administration of the RN hydrographic ships comes under the direction of a number of area Flag Officers (FO) dependent upon the particular ship's home port. They include FO Medway, FO Plymouth, and FO Portsmouth. When these hydrographic ships operate away from their home port in another FO operating area, the ship command also reports to that

area's FO. As an example, HMS HERALD on survey projects in the Scotland area reported to FO Scotland and Northern Ireland; and since HERALD's home port is Portsmouth, it dealt with FO Portsmouth in arranging shipyard repairs and long-term vessel maintenance and finally reported to the Hydrographer on all hydrographic project matters.

The RN operates a fleet of 13 hydrographic survey vessels. This includes four Ocean Survey Ships, also known as "H" class ships, four Coastal Survey Vessels, and seven Inshore Survey Craft. In addition, they have a survey detachment that serves aboard the ice patrol vessel HMS ENDURANCE in the Antartic area.

The Ocean Survey Ships are equipped with WASP helicopters which makes them very versatile by allowing them to: fly their own photogrammetry; quickly establish third-order horizontal control; install tide gages; supply, service, and shift shore stations; and to expedite shore logistics and personnel transfers.

Aboard "H" class ships, the wardroom is not totally composed of hydrographers. These wardrooms also include nonhydrographers including a Weapons Engineering Officer (WEO), a Supply Officer (SO), a Medical Officer (MO), a Mechanical Engineering Officer (MEO), a Flight Commander (FC), and an Instructor Officer (IO). The remaining three or four "Droggies" make up the Wardroom and with the Bosun stand all the underway bridge watches and with the SR's process the data. The Captain and First Lieutenant are the only nonwatchstanding hydrographers on the "H" class vessels.

Now let me discuss a few of the hydrographic procedures that the Admiralty employs in gathering nautical chart data. Basic surveying principles in use by the RN are contained in the two-volume Admiralty Hydrographic Manual. Specific directions and guidance for the day-to-day hydrographic operations in the RN are found in the British Admiralties General Instructions to Hydrographic Surveyors (GIHS).

The data logger in the "H" class vessels simultaneously logs on both reel-to-reel- and cassette-magnetic tapes. Digital depth information, multiple lines of position data, time, gyro heading, log speed, gravity, or magnetics are all types of data that are routinely logged on "H" class vessels. In addition, the shipboard computer system is capable of computing and plotting the ship's position on line on a flatbed plotter. The flatbed plotter has a plotting precision of $\pm$ 0.1 mm.

As mentioned earlier, the British have not fully accepted digital depth information and as a result they continue to have an SR scale depths corrected for tide and velocity from the analog depth recorder trace. The SR calls out these soundings to a hydrographer who manually inks the depths onto a plotting sheet. Normally, the previous 24 hours of sounding data are inked on a composite plotting sheet each succeeding day by the hydrographer who stood that day's 4 to 8 morning watch.

The British do not consider continental shelf surveys as meeting modern survey standards unless they include a thorough side scan sonar search as a

basic part of the survey. As a minimum, this means towing a dual beam side scan sonar fish at a line spacing of 250 meters throughout the survey area. Since each beam of the dual beam sonar covers 300 meters of the bottom, the 250-meter line spacing guarantees that the entire bottom is scanned at least twice. Moreover, in areas of position approximate (PA) wrecks or reported obstructions, an additional 250-meter pattern of side scan sonar lines are run at right angles to the original lines to locate or disprove the feature. This results in attaining 100 percent bottom coverage on four separate lines of hydrography. If a feature is not found after this search, the Charge Hydrographic Surveyor can recommend the deletion of the feature and it can be removed from the chart. The use of side scan sonar to quickly locate or disprove wrecks and bottom obstructions offers the most potential benefit to NOS of all the techniques I saw employed by the RN's Hydrographic Office.

Another attractive procedure in use by the Hydrographer is that of routinely detaching boat camps from the ships. This allows the ship to operate in its most effective manner; sounding and sonaring 24 hours a day on offshore ship hydrography while a detached party performs high-priority inshore harbor launch hydrography independent of the ship. It provides the junior officers in charge of the boat camps an opportunity to exercise responsibility and gives the command an opportunity to evaluate the ability of the junior officers to make command decisions. The boat camps also give numerous members of the ship's company an opportunity for a change of pace from the shipboard routine. Boat camps have been used on occasion in NOS in the past through the initative of various commands. Use of this technique on a continuing basis should be further encouraged, funded, and facilitated by NOS Headquarters.

In conclusion, I found the RN's Hydrographic Department in Taunton, Drake, Whitehall, and in the field to be composed of a group of hydrographers, cartographers, draftsmen, and survey recorders totally dedicated to the efficient production of a very high-quality, thorough hydrographic surveys, nautical charts, and marine information publications. NOS can only benefit by a continued close liaison with such a professional organization. Specifically, I would like to recommend that NOS begin immediately to employ side scan sonar survey techniques and that Headquarters encourage the use of detached boat camps. Finally, I want to publicly thank RADM David W. Haslam, Hydrographer of the Navy, Cdr. R. J. Lowndes, Commanding Officer of HMS HERALD, and all those "Droggies" who treated me with such sincere hospitality throughout my stay in U.K.

DISCUSSION

LCDR RICHARDS: Are there any questions?

CDR CARL FISHER, Chief, Operations Division, AMC: I've got a question on the utilization of side scan, and you did make a recommendation that this be considered.

LCDR RICHARDS: Yes.

CDR FISHER: Did you get any handle at all on the impact of the progress of the survey? In other words, since it's a fairly recent innovation, the British probably have an idea of how long it took them to conduct the survey prior to this time, how complete they felt it was, versus what they do now.

LCDR RICHARDS: The British hydrographic vessels operate at about 12 knots. When you tow side scan, you had to operate at a maximum speed of 6 knots, so very liberally, you could just double the amount of time that you figured you were going to spend on the survey. However, the surveys that I think we are conducting today in congested areas are missing significant obstructions that the British are finding.

As an example of this, the last month and a half I was in HERALD we surveyed the approaches to Glasgow in the River Clyde. They had surveyed this area, using the techniques that we use today, in 1968, the basic hydrographic survey. They had positioned, as a result of this survey, 25 wrecks on the chart. Some were only positions approximate. Some were reported wrecks that they could not locate at that time.

We went back, and in a month and a half of survey time, on a 1-to-36,000 scale survey, and located every one of those 25 wrecks doing the routine survey pattern. And we additionally located six more wrecks that the original survey did not locate. One of the wrecks we detected was in and among very rough bottom pinnacle rocks sticking up in the adjacent area, but you could detect that wreck in among the rocks with the side scan sonar.

The side scan sonar is not used so much to determine a least depth on a wreck or an obstruction, however; it is just used to either locate or disprove its existence. The British have made every survey prior to side scan sonar obsolete. They are resurveying all of their work. So if we reach that point, we would say every bit of work we are doing today will be obsolete as soon as we start employing side scan.

This system would have a very large impact on us, and I don't think it is something we can do tomorrow -- go out and buy 30 side scans and slap them on a ship. But I think we should address side scan as a viable technique, and one we should employ as a basic part of our surveying operation.

CDR FISHER: One additional question: I assume thre is some minimum depth that they would use that technique?

LCDR RICHARDS: Yes.

CDR FISHER: Can't use it in real shallow water. What depth did they use as a cutoff?

LCDR RICHARDS: Generally outside ten meters. It's not effective to use side scan inside ten meters. Perhaps the laser hydrography will handle that part.

CDR FISHER: Thank you.

R.D. SANOCKI: National Ocean Survey: Tom, regarding the boat camp units, is the philosophy of total bottom coverage a part of them also?

LCDR RICHARDS: Yes. They have side scan units for the boat camps, and they use side scan from that 30-foot launch. They don't have any automated systems aboard their launches. Inside ten fathoms they just use echo sounder in order to locate obstructions, and they will do wire drift. They don't use a powered wire sweeping technique. They will drift with the current with wire suspended. That was one thing I didn't get to see and one thing that one of our future exchanges should include, would be experience with the British wire sweeping technique.

MR. SANOCKI: Thank you.

LCDR PICKRELL: Less the absence of a presentation from the FAIRWEATHER on our experience with the exchange, I would like to say, lest they would indicate we were not happy with it, that was certainly not the case. We were very happy to participate on the FAIRWEATHER in the exchange program. Lieutenant Commander David Boutle from the Royal Navy was with us for about the same period of time. He enjoyed his stay, said he learned a lot, and he also feels that the exchange was quite worthwhile, as we on the FAIRWEATHER did.

I don't have a formal presentation to make, but we did prepare a report that has been submitted, and anyone who is interested could get ahold of that report. On our end there are feelings on the exchange program.

LCDR MILLS: Thank you, Tom. That does conclude the formal sessions that we have. I do have a couple of comments I would like to make. If any people come up with any new papers or anything like that, any new techniques, we at the Navy Postgraduate School would be most appreciative if you could drop us a copy. I have been told that out there we are out of touch with reality, so maybe you could keep us in touch with reality a little bit that way.

Also, if any individuals are on the West Coast on any other business, we would certainly like to have you drop by Monterey just to visit or to give a guest lecture on your particular area of expertise. Unfortunately, we don't have very many travel funds to actually fund complete trips, but maybe as a tag-along, we could handle something in that way.

LCDR MILLS: Our next speaker is Lieutenant Commander Tom Richards who graduated from the University of Washington in 1969 with a bachelor's degree in oceanography. Tom joined NOAA's predecessor ESSA in 1969, and since then he has served aboard the MOUNT MITCHELL, the PEIRCE, and was Operations and Executive Officer aboard the RAINER.

Other assignments have included Chief of the Pacific Tide Party, Chief of Hydrographic Surveys Branch, and is presently Chief of the Hydrographic Surveys Requirements Branch. From June to December, 1980, Tom was part of the US-United Kingdom exchange program, and it is this exchange program which Tom is going to speak to us about today.

You will notice on the agenda that Lieutenant Commander Alan Pickrell is also on there. Al is not going to participate in the presentation. He is Operations Officer aboard the FAIRWEATHER, and the FAIRWEATHER was the ship that the British exchange officer was aboard. So Tom has assured me that any questions he can't answer at the end of his presentation, that Al will pick right up on.

Tom?

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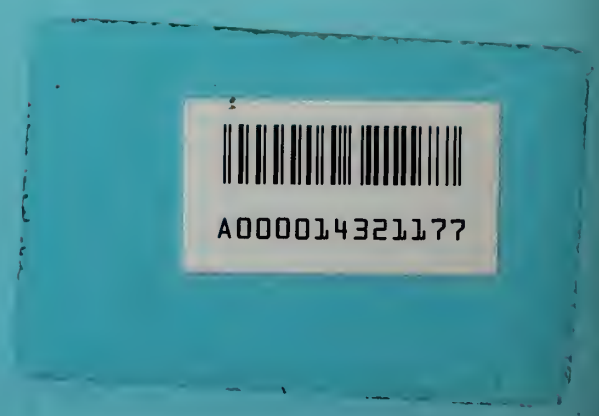
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